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ABSTRACT

Controversies involving science, technology, and society are explored in 15 articles written by historians, social scientists, management consultants, engineers, and experts in the history of science. Technological development in an historical context is the central theme of the booklet. Major issues discussed include effects, preconditions, and sources of technological change. The collection of articles is part of a series developed to present college level course material to the general public through cooperation of newspapers, public television, and 300 participating colleges and universities. Titles of the articles are: "Technology on Trial," by John G. Burke; "Silent Revolutions," by Peter F. Drucker; "How Terribly Technical," by Derek de Solla Price; "Occupational Destinies," by Joseph C. Gies; "Culture: The Link Between Nature and Technology," by Clarence J. Glacken; "The Influence of Societal Values," by Edwin T. Layton, Jr.; "Technology, Population, and Resources," by Kingsley Davis; "Incentives for Innovation: Technology and the Economy," by Nathan Rosenberg; "Science and Technology," by Robert P. Multhauf; "The Imperatives of Engineering," by Eugene S. Ferguson; "Wars: Hot and Cold," by Herbert F. York and G. Allen Greb; "The Government's Role in Technological Change," by A. Hunter Dupree; "The Mystery of Inventiveness," by Lynn White, Jr.; "Technology and the Seamless Web: Ethical Dilemmas," by Bertram Morris; and "Assessing and Directing Technology," by Melvin Kranzberg. Background information on the authors is presented following each article. (DB)

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Article Booklet
for the
Eleventh Course by Newspaper

Connections: Technology and Change

John G. Burke
Peter F. Drucker
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Preface

Cultural changes in the past few decades have provoked bitter criticisms of science and technology, which are blamed for such undesirable trends in our society as materialism, job dissatisfaction, loss of individuality, invasion of privacy, and destruction of our environment. The fifteen articles in this booklet shed light on the controversies involving science, technology, and society by exploring the nature of technological development in a historical context and in its relation to contemporary problems. The effects, preconditions, and sources of technological change are among the issues probed.

These articles were originally written for the eleventh Course by Newspaper, CONNECTIONS: TECHNOLOGY AND CHANGE, offered in newspapers throughout the country for the first time in fall 1979. John G. Burke, Professor of History at the University of California, Los Angeles, coordinated this course.

Courses by Newspaper (CbN), a national program originated and administered by University Extension, University of California, San Diego, develops newspaper articles and related educational materials that are used as the basis of college-level courses. Hundreds of newspapers and participating colleges and universities throughout the country cooperate in presenting these courses to the general public.

Each course features a series of weekly newspaper articles, written by distinguished university scholars and other experts. Supplementary materials include a book of readings and a study guide for interested readers, with a Source Book available for community discussion leaders and instructors.

In addition, for this course a related ten-part series of television programs, "Connections," has been produced by BBC and Time Life Films for airing over the Public Broadcasting Service in fall 1979; the programs are also available for purchase or rent from Time Life Multimedia. A Viewer's Guide, relating the print and video materials, and a narrative text, *Connections,* by James Burke, the TV-series narrator, are also available.

Colleges within the circulation area of participating newspapers offer the opportunity for readers to meet with local professors and earn college credit. If no local college or university is participating, credit arrangements can be made with the Department of Independent Study, University of Minnesota, Minneapolis, Minnesota 55455.

The first Course by Newspaper, *America and the Future of Man,* was offered in the fall of 1973. Subsequent courses have included:

In Search of the American Dream
Two segments of *The American Issues Forum*
Oceans: Our Continuing Frontier
Moral Choices in Contemporary Society
Crime and Justice in America
Popular Culture: Mirror of American Life
Taxation: Myths and Realities
Death and Dying: Challenge and Change

To date, approximately 1250 newspapers and 800 colleges and universities have presented the courses. Approximately 15 million people read the articles for each course and almost fifty thousand persons have earned credit through Courses by Newspaper.

Courses by Newspaper has been funded since its inception by the National Endowment for the Humanities, an independent federal agency created in 1965 to support education, research, and public activity in the humanities. Supplemental funding for individual courses has been provided by the Exxon Education Foundation and the Center for Studies of Crime and Delinquency, National Institute for Mental Health. We gratefully acknowledge their support.

We also wish to thank United Press International, which has cooperated with CbN since 1975 in distributing the articles to participating newspapers across the country.

The views presented in these articles, however, are those of the authors only and do not necessarily reflect the views of the University of California or the funding and distributing agencies.

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1. Technology on Trial

JOHN G. BURKE

Smog! Water pollution! Excessive noise! Urban filth! Shoddy products! Lethal food additives! Radioactive wastes! Genetic manipulation! Dehumanization!

These are the results, critics charge, of our blind faith in technological progress. Rebuttals calling attention to our high standard of living, improved health, longer life spans, better working conditions, and increased educational opportunities do not still the critics' voices.

Technology is on trial.

The most ominous assertion is that technology is now completely out of human control. Technology, the prosecution says, has become an independent entity, a thing apart from humans who gave it birth. We have become cogs in a huge system of production and consumption, a machine having no human purpose. Certainly, modern technology gives most of us a means of livelihood, food, shelter, and leisure to watch TV. But the price we pay for these material satisfactions, it is said, is our freedom.

Technology, critics declare, not only shapes and directs every aspect of our lives, but threatens the very existence of the human species. Our increasing love affair with rationality and efficiency—that is, science and engineering—is responsible for creating this technological monstrosity. We are thus caught in a web of our own making.

One possible escape route may be open, declare the anti-technologists, but only if we act quickly and forcefully. Repudiate modern science and high technology. Return to a simpler way of life.

Even if these prophets of doom are exaggerating or are mistaken, there are many signs, such as pollution, which indicate that something has gone wrong. We are constantly surprised by technology's shortcomings. Dangerously defective tires nullify the safety advantages of mandatory seat belts. Cancer-producing food additives are banned, and later their replacements are found to be just as lethal.

Technology resembles the Hydra, the awesome nine-headed beast finally slain by Hercules, which grew two heads from the root of each he struck off.

Will we succeed in overcoming our problems as Hercules did his? Do humans have enough resilience to maintain freedom and choice in spite of burgeoning technology?

Assertions and predictions about technology usually are based on several assumptions that are difficult if not impossible to prove. One is that technological change is taking place more rapidly than in the past. Another is that technological change has a much greater social impact than ever before. A third is that scientific research and development are exclusively responsible for present technological innovations.

A useful way of assessing our present situation, of judging whether it is indeed unique, is to look at technological development in a historical context and in its relation to contemporary problems. This series of fifteen articles has that goal.

Effects of Technology

Three of the more important effects of technological advance are the increasing complexity of our civilization, the changes in our culture and institutions, and the impact of innovations on work. The complexity of our technological society, indeed, is one of the reasons critics give either for our loss of control or for their charge that the system is manipulated for the benefit of a scientific-technological elite. One frequently cited example is the 1965 New York blackout, which plunged the city into darkness for hours before power was restored, and the cause of which stumped experts for days.

Is complexity a novel feature of modern technology?

Similarly, societal and institutional changes are apparently occurring with astonishing rapidity. A century ago, for example, any proposal for a U.S. Department of Energy would have appeared ludicrous. But now, as we worry about an energy shortage, it has become a necessity.

Have advancing technologies always had the effect of altering cultures? Has the pace of change quickened?

Only when we look to the past do we realize fully how very different our methods of producing goods are from those of our forebears. Technology has unquestionably affected the work process. However, the important questions are whether our labor has become more individually rewarding and more socially beneficial.

Preconditions

Yet, effects do not occur without preconditions. One is our physical enviroment, which is necessary to life and crucial in the development of technology. The exploitation and misuse of the environment is one of our most urgent problems.

How have past cultures or those in other parts of the world come to terms with nature or arrived at a compromise between the environment and technological progress? Does high technology inevitably entail enviromental deterioration?

Another apparent precondition of technological advance is the size, distribution, and migration of populations. Some critics maintain that the size of our population and its increasing concentration in urban areas are primarily responsible for environmental pollution. Others declare that without technological progress the growing populations in developing nations will perish. Yet historically, the links between technological progress and population growth are puzzling.

What advice, if any, should we give to developing nations? Or, to ourselves?

Societal values constitute a third precondition of

technological innovation. For example, gunpowder, invented in China, was not used there for firearms. When it appeared in Western Europe, however, military engineers immediately grasped its military potentialities.

Why do some cultures accept technological innovations that others reject?

Sources of Technological Change

Given these preconditions, however, what stimulates technological progress, and who or which institutions accomplish innovation?

Humanitarian concerns, the spirit of adventure, or the wish to transform idleness to active leisure, have produced some innovations. But the principal agencies of technological innovation are economic activity, science, engineering, war, and government, although some economists would maintain that all of these ultimately can be lumped under economic activity.

The desire to satisfy material needs, individual or social, has always been a major source of innovation. In western cultures, luxuries have become necessities with resulting economic growth. Indeed, some critics blame the "growth ethic" for both environmental deterioration and for the purported decline in the quality of life.

To what extent is this ethic the cause of our difficulties?

From small beginnings in the seventeenth century, scientific research activity has now grown to substantial size. On the one hand, the rational and objective approach of scientists provokes criticism; on the other, the discoveries, which give rise to technological innovation, cause worry.

How has science grown? What is its interaction with technology? How do scientists perceive themselves? And, inasmuch as science receives the credit or blame for innovation, what is the engineers' role, and to what extent should their activities cause concern?

War has always encouraged technological innovation, not just in the development of new weapons, but also in stimulating new industries and methods that have profoundly affected society. Military needs were the chief stimuli for the development of aircraft, space ships, and computers.

Similarly, governments have encouraged innovations through the patent system, agricultural experiment stations, and agencies that aid industry.

To what degree does this activity, both military and civilian, contribute to our present problems?

The subjects described above and the questions raised comprise the main body of this series of articles. The final three articles will consider both the past and the future prospect. They will investigate the nature of inventive activity, the relation of technology to ethical principles, and the merits and shortcomings of current attempts to direct the course of technological development for human purposes.

Serious public consideration of these issues and participation in the on-going debates is necessary. For it is only through our collective wisdom that the problems concerning technological advance and its effects can be resolved.

ABOUT THE AUTHOR

JOHN G. BURKE is Professor of History at the University of California, Los Angeles, where he has also served as Dean of the Division of Social Sciences and Dean of the College of Letters and Science. He joined the faculty there in 1962 after a successful business career. He holds degrees in both metallurgy and history, and his awards include three grants from the National Endowment for the Humanities for seminars on Technology, Society, and Values in Twentieth Century America. Among his publications are *Origins of the Science of Crystals; The Science of Minerals in the Age of Jefferson* (coauthored with J. C. Greene); and *The New Technology and Human Values*.

2. Silent Revolutions

PETER F. DRUCKER

Major technological developments—from television and computers to satellites and nuclear energy—are profoundly affecting the way we live. They are thereby causing concern about the social impact of technological change.

Technology does indeed often have great social or political impact. But it is far from predictable whether this or that technology will have impact, let alone what it will be. The impact depends as much on the response of people and of cultures as it does on the new technology.

For example, the first "women's liberation" occurred in the 11th and 12th centuries. In the history books, this sharp change in the position of women is recorded in terms of literature, religion, or law. For the troubadour who emerged in Southern France, woman was no longer a "sex object," but an object of adoration to whom he addressed his poems from afar (or at least pretended to).

In Christianity, the Virgin Mary replaced God the Father as the central figure in popular worship and in religious art. And legally, women acquired property rights as widows, the right to maintain property they brought into the marriage, and the right to their own earnings.

The Spinster

But the underlying cause of these tremendous social changes was a technological innovation in France—the spinning wheel. With it came the "spinster"—actually, anyone who spins, although we use the word today to denote an unmarried woman who is no longer young.

Spinning has been women's work from time immemorial—we still speak of the "distaff" side of the house. But spinning on the distaff was inefficient. It took ten spinsters with distaffs to keep one weaver going. With the spinning wheel, the relationship was reversed. One spinster could supply half a dozen weavers with yarn.

When spinsters became productive, they became independent. Suddenly, a woman could be in society and be respectable without being dependent upon a male. Until then, only a nun or prostitute could survive without being a wife or concubine. Girls, therefore, had to be betrothed in infancy. Now they could remain single until old enough to choose whom to marry or even not marry at all. They could be "spinsters."

The great changes in culture, in religious worship, and in law then followed in short order.

The Second Women's Lib

The second "women's liberation," that of today, also has its roots in technological innovation—in the sewing machine, the typewriter, and the telephone.

Before the sewing machine was invented, a little over a hundred years ago, sewing was the hardest, most time-consuming job of the housewife. Only the very rich could afford to have their clothes made by a tailor. The rest had to make and mend their own clothes. The farm wife or worker's wife of 1860 spent four to six hours a day plying the needle.

The sewing machine cut this time to approximately 30 minutes a day. It also made clothes so cheap—cutting prices by more than three-quarters—that even ordinary people could afford "store-bought" clothes.

The typewriter and the telephone, by creating middle-class employment opportunities outside the home, made it possible, as had the spinning wheel eight hundred years earlier, for "respectable" women to earn their living without being dependent upon a male. Even in Dickens' last novel, written around 1870, there are only male clerks in offices. "Respectable" women did not go out without an escort.

Twenty-five years later, an advertisement for a "clerk" generally meant a woman rather than a man; and "respectable" women were going to work by themselves, traveling by themselves, and altogether leading lives of their own. Higher education for women, considered a luxury or an ornament in Victorian times, soon became a necessity. The demand for the vote, for equality before the law, and for equality in careers inevitably followed.

The First Civilization

But perhaps the most important example of the connection between technology and social order is the first true "civilization," that of the irrigation cities of antiquity—of Egypt along the Nile five or six thousand years ago; of Mesopotamia about the same time; of the Indus Valley a thousand years or so later; and of Southern China, from which Chinese civilization arose four thousand years ago.

What made the irrigation city possible was technology: the ability to erect and maintain civil engineering works to lead the flood waters of the rivers to the land, to prevent their running back into the river again, and to circulate them.

These irrigation works—the first, and perhaps the most impressive, achievements of "modern" technology—required measurement, which led to the development of geometry. They required ability to forecast the flood, that is, a calendar and astronomy. They brought people together into very large settlements and thus required water supply, sanitation, city walls, and public buildings.

They required specialists: scientists, physicians, bureaucrats, tax collectors, lawyers, scribes, teachers, and engineers. The irrigation city required writing to record contracts and tax receipts. It required law—and the codes developed then, whether in Babylon or in China, would still serve most needs of modern commerce today. The irrigation city required law courts to settle disputes and police to maintain safety.

Above all, irrigation developed city and citizen. It

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developed a common deity, where there had been only tribal gods. And from this came the belief in a universal God of all mankind, and indeed the idea of "Mankind" itself.

In other words, the irrigation city developed what we still call "civilization." And its foundation was technology.

Technology and Society

These examples show, first, that technology is not something outside of society. It is society itself. But it does not "determine" society and culture. It must fit both to become effective technology.

The spinning wheel was an obvious invention once the carriage wheel and the potter's wheel had been introduced—several thousand years before the spinning wheel replaced the distaff. Society was simply not receptive; the lady of the house spinning with her daughters and maids—a scene the Homeric Epics depict again and again—fulfilled important functions that society did not want to do without.

Secondly, these examples show that technology provides only options. The spinning wheel diffused rapidly throughout the Old World. Yet it had social and cultural impacts only in the areas of Western Catholicism—not in the regions of Greek Catholicism. It had none at all outside the Christian world, that is in China or India.

The irrigation city similarly evoked different social and political responses. In Egypt, a religious bureaucracy emerged, but there were no political or social theories and no secular institutions. In China, the irrigation city brought about great political and social theory—the Confucian concept of social harmony, based on interpersonal relations and aiming to make human society conform to a pre-established harmony of the universe.

Equally great was the impact in the Mid-East. In Sumeria and Babylonia it was soon seen that the centralized governance of the irrigation city could become a tyranny, exploiting the weak and poor, but also a force for good, the engine of justice and compassion. And political philosophy as we now know it thus arose in the irrigation city of Mesopotamia and thence in Greece.

These illustrations show that technology is first and foremost a "humanity." Technologies are not created by nature or by elves in the Black Forest. They are created by humans. They are extensions of Man, to be used by humanity.

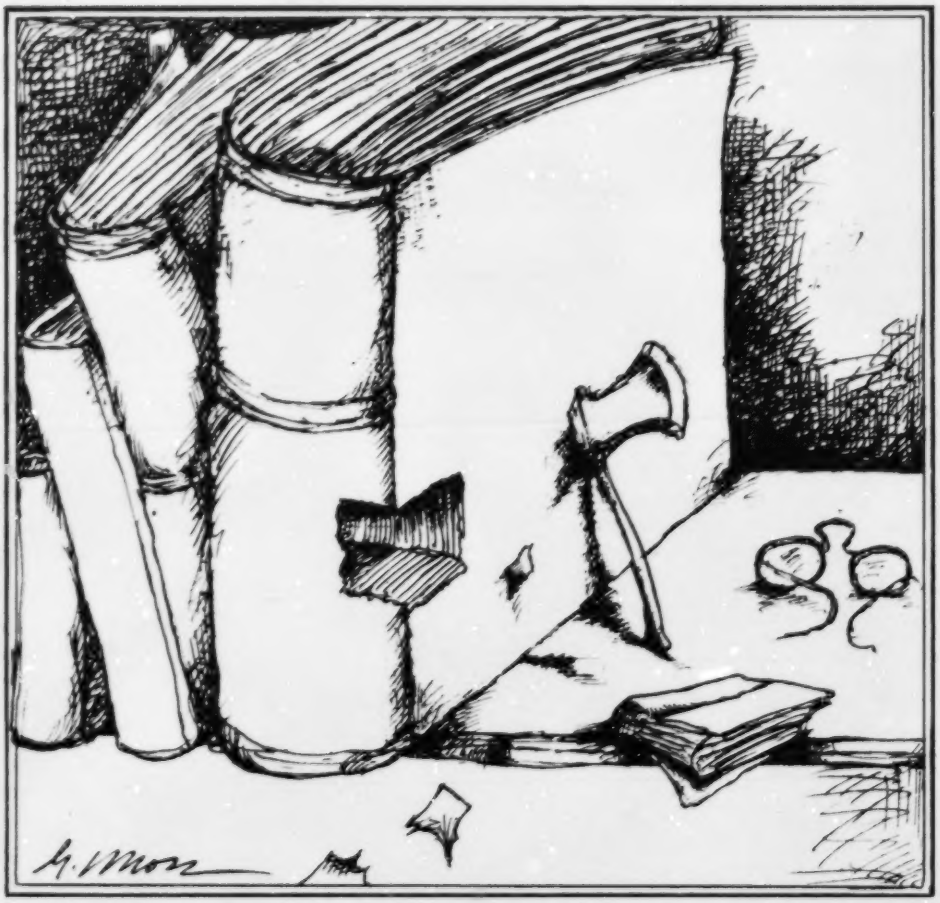
Alfred Russell Wallace, who with Charles Darwin formulated the theory of natural selection, said "Man is the only animal capable of purposeful evolution; he makes tools." These tools bespeak human needs and values. They give us new performance and new survival capacity. They make us, in effect, a different animal.

Thus they pose new human options, create new human opportunities, and demand new human answers.

Technology liberates by giving us choices.

ABOUT THE AUTHOR

PETER F. DRUCKER has been Clarke Professor of Social Science and Management at Claremont Graduate School (California) since 1971. He previously taught in the Graduate Business School of New York University, where he still serves as Distinguished University Lecturer. A management consultant to both private industry and government, he has been awarded ten honorary doctorates from American and foreign universities. He is the author of more than a dozen books, including *The Future of Industrial Man; The Age of Discontinuity; Technology, Management, and Society;* and, most recently, *Adventures of a Bystander.*



3. How Terribly Technical!

DEREK DE SOLLA PRICE

The force of science and technology controls much of the modern world. It holds the purse-strings of civilization, forms the basis of military might, and dominates the quality of life and the possibilities of the future for every person on earth.

Why then does it seem beyond the control of the people, beyond their comprehension? Why do scientists talk learned gobbledegook and behave like an elite power group, protecting their mysteries and the basis of their power? At the same time, why does the mass of humanity seem herded into a world of nuclear rebellion, megadeaths, food additives, conspicuous technological consumption, and mindless computerization?

The rapid growth of science and our increasing dependence on high technology have produced a widening gap between scientists and the general public—a gap that has been only partially bridged by education—and that only in the few most developed nations.

From the beginning science and technology were like any other field in which some people were cleverer that others. Right at the start of history in Mesopotamia five thousand years ago, a most sophisticated and complicated craft of arithmetic and a mathematical treatment of astronomy developed. It was incredibly successful and accurate—and as incomprehensible to the common persons as higher mathematics has been ever since. It set a pattern that has persisted right down to modern mathematical physics and the other sciences related to it.

Mathematics from the start involved not only a special talent but also a long, difficult investment in years of learning. We do not know the practical function—if any—that these mathematical skills had. Were the learned Mesopotamian priests and the Greeks, Arabs, and medieval and renaissance scholars that followed them deliberately hiding their skills from the common people? There was no conspiracy of an elite.

Two Revolutions

In the course of history two great changes in technology caused scientific knowledge to become more elite. Around 1500 AD came the Gutenberg Printing Revolution. The book very quickly changed the entire society. Presses were built and run by craftspeople in the cities rather than by scholars in monasteries and universities, and both the writers and the readers of the new books were a new class.

What happened with the opening up of science to its new public? Certainly there was a general democratization, but the arcane mysteries of highly technical knowledge persisted.

Then in the 17th century came the Scientific Revolution. The telescope and other instruments changed the status of our attempts to understand the universe. Before, it had depended only on brain-power, and all philosophers worked with the same evidence. Suddenly Galileo saw mountains on the moon, satellites around Jupiter, thousands of stars nobody had seen before.

It was a discovery of an artificial method of revelation (which the church could not then accept), and it changed the universe that was to be explained. From then till now, the effect of technology upon science has been the most powerful means of improving our understanding of both the natural universe and manmade technologies.

Scientific Journals

To cope with the new flood of learning, enthusiasts began to band together into societies. Making use of the presses, they began a fresh tradition of scientific journals in which they published items of new knowledge as they came in.

At first it seemed illicit to publish atoms of knowledge in this way without maturing them into a life's work book, but the method flourished particularly well with science, and a society of writers and readers of scientific research papers grew with enormous rapidity. The papers themselves became a world body of literature incorporating the new understanding of science and technologies.

Had the technologies of communication and instruments bred a new elite? Certainly they developed a new set of words and a special impersonal literary style appropriate for new thoughts. Some scientists were noblemen, physicians, clergymen, professors, but others were artisan instrument-makers, working surveyors and navigators, and mechanics or just enthusiasts, like modern stamp collectors or birdwatchers.

What happened, however, was that the enormously accelerated pace of new knowledge and ever-increasing sophistication of theory continuously removed the new scientific understanding from the majority of people simply because with each generation, despite increased education, more had to be learned, more skills had to be acquired.

By the 18th century the exponential growth of new knowledge (doubling every ten years) and new technologies had reached the point where workers like the Luddites in England broke the machines that threatened their livelihood. Even the scientists could not keep up.

Encyclopaedias and summary abstracts of research papers to wrap up the learning into digestible form offered one solution. The great French Encyclopaedia was frankly political in its attitude to the technical knowledge of all skilled trades, publishing all the alleged secrets that might oppress the populace by forcing them to toil as apprentices rather than read and become masters. In the same spirit, new democratic elements in society forced disclosure of technical secrets as a published patent, in exchange for a commercial monopoly on the new device.

Needless to say, the encyclopaedias and patents did not solve the problems of nonscientists, but merely enabled the basic problem of availability of knowledge to grow another stage.

New Technologies

Around 1800 there was another crucial growth in science: Galvani and Volta, looking for the secrets of life, found current electricity. Within a single generation, electricity transformed chemistry into a wealth of new substances and new understandings. The 19th century saw such new technologies as fertilizers and soil chemistry, dye chemistry and explosives, steam engines and locomotives, as well as electrical energy.

The steam engine had grown from a "low" (nonscientific) technology of water-pumps, but the chemical and electrical high technologies required the scientific knowledge of the day. In industrial nations education had to be expanded to produce the technical workers, and popularization prepared the public for the new age.

By 1900 the wealth of the major nations and the quality of life for their people were linked more to the new technologies, low and high, of manufacture than to the natural wealth of the land. Increased understanding brought forth more and more high technologies.

By 1950 the wealth and power of nations and lives of all people began to depend ever more on the high technologies and their inevitable link with sciences that were increasingly technical and learned, and beyond the understanding of the general public.

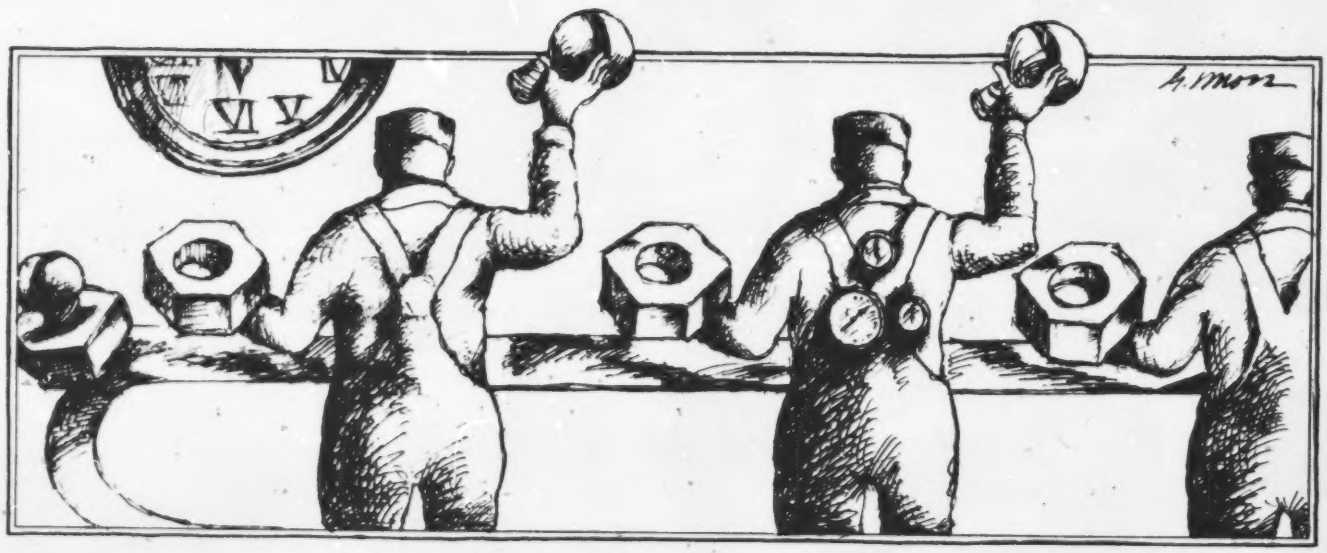
In the last quarter century, new efforts to popularize science and make it understandable to the lay person have lent increased urgency to the problem of the closed shop of science. But workers suffering from the impact of new technologies, appropriate and inappropriate, have broken the machines like the original Luddites. Today the popular rebellion is against nuclear reactors and genetic engineering, and in nations like Iran, everything technical.

We cannot all be scientists (nor want to), and we cannot ignore the existence of the world's stock of science. But we are of necessity all consumers of more or less free choice in the technological world.

The traditional answer to ignorant domination by technologies is education, but it is still only a partial solution of an irritating and desperate problem—one that we may never be able to solve completely.

ABOUT THE AUTHOR

DEREK DE SOLLA PRICE has been Avalon Professor of the History of Science at Yale University since 1959. He holds doctorates in both experimental physics and in the history of science. A consultant on science policy to several governments and international bodies, he has published some two hundred scientific papers and six books, including *Science Since Babylon* and *Little Science, Big Science*.



4. Occupational Destinies

JOSEPH C. GIES

Technological innovations—new tools, new machines, new processes—affect not only human society but, directly and immediately, the producing workers. Today, it is possible to envision a society in which technology will liberate workers from much of the physical drudgery and boredom that have marked their lives in the past.

Better tools permit workers to produce more (and better) work; machines replacing tools save their labor and multiply their production; and computer-programmed automated factories turn them into monitoring engineers, employing mental more than physical skills.

Nevertheless, workers typically have not welcomed innovations in production technology—far from it. Nor are they entirely mistaken in their apprehensions about new techniques. Quite apart from their principal fear—that it may bring unemployment—new technology may have unforeseen effects on their working lives and personal destinies.

The outstanding historical example of the impact of changing technology on workers' lives is the development of factory mass production. Even while creating the abundance that has transformed the modern world, mass production has had a dehumanizing effect which governments, workers' organizations, enlightened management, and modern social science still seek to mitigate.

Fighting the Factories

The modern factory system has an ancestry going back many centuries. Medieval wool merchants in Flanders and Italy began "putting out" their wool successively to spinners, weavers, fullers, and dyers in what amounted to factories scattered through a town. The system foreshadowed the true factory both in increased volume of production and in the stimulation of class conflict. By no coincidence, history's first strike, in 1245, was by weavers of Douai, in Flanders.

The "Commercial Revolution" in which the Flemish wool entrepreneurs participated provided the basis for the later Industrial Revolution centered in 18th-century Britain. Spinning and weaving there were mechanized and steam-powered, multiplying productivity but alarming the hand weavers. In the early 19th century, bands of "Luddites," fearing loss of jobs, tried to destroy the new machinery but they were brutally suppressed by government troops.

In France, workers kicked machines to pieces with their heavy wooden shoes, or "sabots"—giving rise to the word "sabotage." Similar worker protests occurred in Germany and were memorialized by Nobel prize–winner Gerhardt Hauptmann in his drama "The Weavers."

British workers resisted another innovation: work discipline. At his celebrated pottery works at Etruria, England, Josiah Wedgwood, in the latter half of the 18th century, was one of the first to divide his labor force into sequential groups—potters, painters, firers, finishers—achieving both increased production and enhanced quality.

But the new arrangement required that workers conform to the pattern imposed by the flow of production. Previously, as craftsmen, each performing the whole range of functions in pottery making, the workers had frequently "kept St. Monday" (taken Monday off), and on other days had sometimes deserted their benches for an ale or a game of handball. Wedgwood posted rules and levied fines, but remained chronically vexed by labor troubles.

Loss of Dignity

As powered machines supplanted skill with semi-skill or lack of skill in industry after industry, workers in Britain and elsewhere lost their old sense of creativity and even their old dignity. An observer at a British trades-union congress in 1890 recorded the difference in appearance between the old aristocracy of craft unionists, with their respectable dress, often including top hats and watch chains, and the "new" unionists, the shabby, nondescript factory workers.

In America the industrial revolution at first produced a quite different effect. The wealth of natural resources and severe shortage of labor made the country highly receptive to the textile machinery spirited out of Britain (against ineffective laws forbidding its export) by Samuel Slater, a youthful immigrant of 1789 who became the "Father of American Manufacture." Native mechanics such as David Wilkinson and Paul Moody added Yankee improvements and helped found America's own machine-tool industry, that is, machines to make machines.

It was not surprising, therefore, that the next major production breakthrough, interchangeable parts manufacture, achieved its triumph in America. The concept had originated in France and Britain, where experiments had indicated its promise, but craft-minded European industry held back. In America, Eli Whitney, John Hall, and others developed it in the government-supported arms industry. It soon gravitated to production of iron stoves, sewing machines, and farm implements.

The American System

By the time Henry Ford appeared on the industrial scene about 1900, interchangeable-parts manufacture was known throughout the world as "the American system." From Chicago and Cincinnati meat packing plants, Ford got the inspiration for his assembly line, which brought parts directly to the workers in a continuous flow.

No rules needed posting, no fines were required. The moving line's inexorable pace enslaved the men feeding

it, exacting repetitive functions performed with an inhuman consistency. Assembly-line workers were turned into the human machines satirized by Charlie Chaplin in his 1936 film "Modern Times."

Meanwhile, at the turn of the century, a Philadelphia engineer, Frederick W. Taylor, devised a way to increase steel workers' output by minutely analyzing their jobs. By following Taylor's instructions faithfully, a worker could substantially improve his piecework earnings. But "Taylorism," or scientific management, copied and often abused, won a reputation for efficiency at the expense of humanity.

A glimmer of insight into worker psychology came in the 1920s, quite by accident. In studying the effects of improved illumination on worker performance at the Western Electric Company plant at Hawthorne, Illinois, Elton Mayo was astonished to find that a control group, under the old lighting, improved its production as much as did an experimental group under better lighting. The "Hawthorne effect" showed that workers responded with better performance to the mere fact of being consulted, asked to cooperate, dealt with as human beings.

Further experiments explored the relationship between man and machine and the worker subculture, virtually creating a new sociology. Human-factors engineering, an outgrowth of Taylorism and the Hawthorne experiment, sought to design machinery and equipment for maximum ease, convenience, and suitability.

Automation

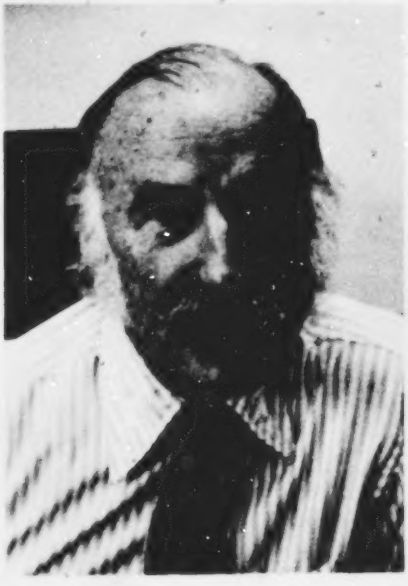
The most recent stage in mass production, automation, came immediately following World War II (though machines basic to factory automation go back to the Waltham Company in the 1880s). Workers' resistance in some industries, such as railroading and printing, has brought considerable conflict. Yet overall, automation's impact on employment so far has proved limited.

Meanwhile, factory working conditions continue to cry out for improvement, particularly the reduction of heavy labor, noise, and the provision of amenities. "Flexitime," by which workers are allowed to arrange their own schedules within certain limits, has enjoyed success in a number of U.S. and European plants and offices, measured in part by a reduction in absenteeism.

"Job enrichment," aimed at combatting "anomie"—the boredom of repetitive work—has also had some success, though in its more radical forms, such as non-assembly-line production of automobiles in Italy and Sweden, the outcome is not yet clear. Essentially the recent experiments have been attempts to exploit the principles discovered by Elton Mayo by providing greater scope for personal achievement and recognition for the workers.

In recent decades as in times past, however, such conscious efforts have been less significant in altering the worker's relation to work than the large-scale and usually unpredictable changes imposed by the general direction of technology and economics. These include the shift toward the service industries and high-technology clerical jobs, and from fabrication to processing industries, such as chemicals, plastics, and synthetics, in which automation flourishes.

These changes and the rapid strides made by industrial robots, which perform mechanically some of the functions previously performed by humans, give cause for hope that in the not too distant future physical drudgery and anomie may both be eliminated.



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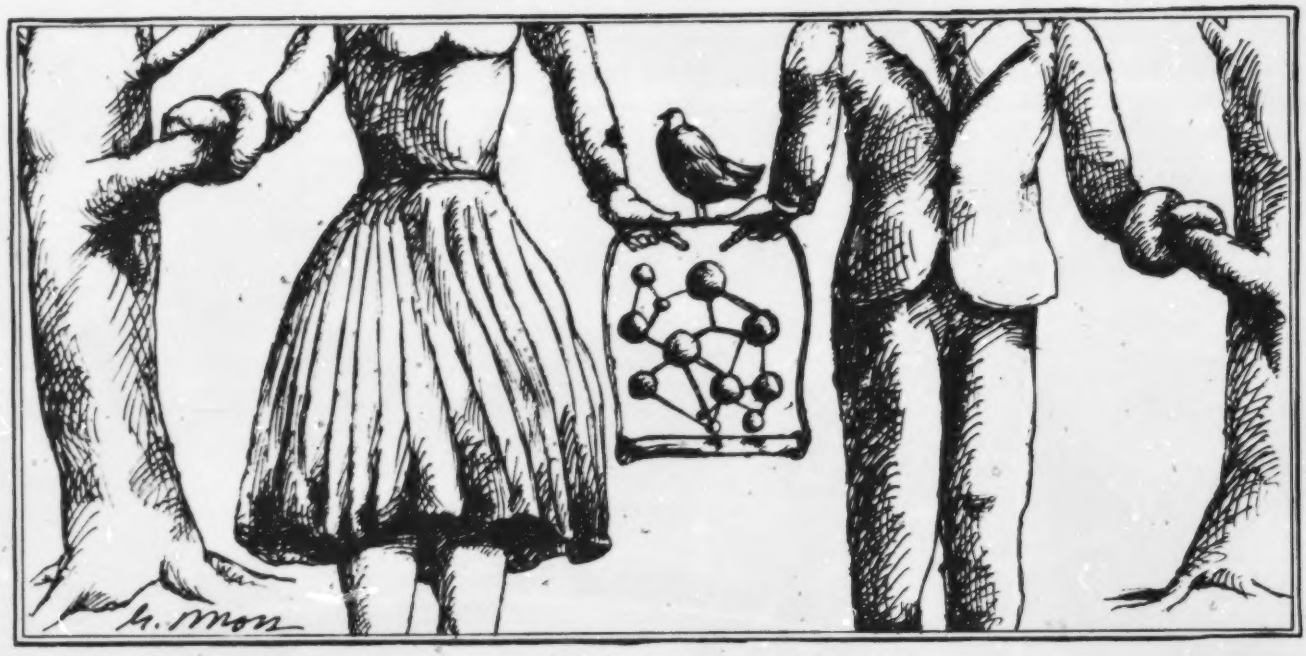


5. Culture: The Link Between Nature and Technology

CLARENCE J. GLACKEN

We live in a period in which technology is complex and rapidly changing and are inclined to think of it in terms of computers, machine and precision tools, and electronics. However, even in prehistoric times, humans used simple but powerful technologies, such as fire, to modify nature.

The relationship between nature and technology, whether simple or complex, can be understood only in terms of culture—those patterns of behavior and thought common to a people.

Culture is the crucial link between nature and technology. Culture determines both how we use and modify nature and how we think about it.

Let us think of the earth's surface as if it were a huge relief map. We can place thousands of overlays on it to show various distributions: physical elements like climates, mountains, minerals, and oceans; organic elements like forests, swamps, and cultivated lands; cultural elements like settlements, religions, languages, and technologies.

Any inhabited area on the earth's surface is composed of different combinations of these distributions. We may have Spanish-speaking Catholic farmers with a few sheep living on a dry plateau, and Hindus, to whom cows are sacred, speaking English and growing rice where monsoon rains cause disastrous floods.

The existence of these mosaics is the reason we cannot profitably talk abstractly about technology and nature. There is no direct relationship between them except through the medium of culture.

Values and Concepts

Throughout history, and up to the present, different cultures have valued and sought in nature different things. For example, the native Americans did not search for plutonium as we do now. We no longer seek whale oil for lamps, as our forebears did.

Every culture, prehistoric, primitive, and civilized, so far as we know, has developed a conception of nature. In primitive and prehistoric cultures, it may be a form of nature worship, or nature-spirits, or the personification of nature like "Mother Earth." Some modern societies have a purely utilitarian conception of nature, as a resource there for human beings to use. Others may think of it esthetically or biologically or both, as a beautiful, harmonious but fragile system of interlocking physical and biological elements.

Early Technologies

If we look back to prehistoric times, two technologies that modified nature stand out: plant and animal domestication, and the use of fire.

The domestication of plants and animals began the long series of experiments in breeding which have completely transformed the nature of organic life on earth. Millions of square miles are now in cultivated crops; they are vast substitutions for what was there before the intervention of human beings with their tools. With animal domestication, the dog, the horse, the ox became agents in the modification of nature by human beings.

The use of fire to clear land for grazing, to deforest it for agriculture or other purposes, has been of the utmost importance. We cannot study the resources and geography of large parts of Southeast Asia, Latin America, and Africa—especially south of the Sahara—without recognizing that fire, now as in the past, is an agent of significant environmental change. Peole living in a culture like our own, dependent on advanced technologies based on applications of theoretical science, either overlook these fundamental facts or are unaware of them.

Thus, there has been a tendency to think that technology is a modern phenomenon coming from the basic inventions, like the steam engine, of the Industrial Revolution in the latter part of the 18th century, and that before then, humanity relied primarily on its own and animal power.

This belief ignores the role of water and wind in the history of technology. Water management by aqueducts, canals, stream diversion, and draining is ancient. Drainage has been one of the fundamental activities of the human race in many parts of the earth, and its cumulative effects have been to make the earth drier.

Problems and Solutions

Have such inventions and technologies been developed as solutions to problems that nature creates for the human race? This is an influential and ancient idea, which we can restate in the words of the old and familiar proverb, "Necessity is the mother of invention."

We do not know if it is or not, or if necessity explains the origin of technology. The late geographer Carl Sauer in his classic study, *Agricultural Origins and Dispersals,* argued that leisure may have been necessary for the discoveries leading to plant domestication: "The needy and miserable societies are not inventive, for they lack the leisure for reflection, experimentation, and discussion." One might think the wheel would be an excellent example of necessity being the mother of invention, but it was not known as a technological device in the New World before Columbus.

Since ancient times, people exploiting the earth's resources have tried to interpret what they have done and have often philosophized about it. Such interpretations go back in China at least to the time of Mencius (4th-3rd centuries B.C.) and in Greece to Plato (5th-4th centuries B.C.). Both men were interested in the effects of deforestation.

In the last two centuries an enormous literature covering many parts of the world has come to light regarding these environmental changes through various technologies, simple and complex; it had been slowly accumulating since antiquity.

Conflicting Views

Our conclusions regarding nature and technology depend partly on how we look at history. If we study the history of technology, we are apt to be impressed by inventions, successes and failures, anticipations, improvements, and applications. Our perspectives would be different were we to study the history of the modification of the earth by human beings and their technologies.

The first view of history is likely to show purpose and rational acts based on theory or experience; the second, to uncover unforeseen consequences of human intrusions into the natural world.

In our times, we are seeing a dramatic meeting of these historic and often opposing streams of thought: (1) an optimistic belief that science and technology, through directed and rational change of physical and organic nature, can manage the environment for continuing human use indefinitely and (2) a pessimistic view based on an organic conception of nature whose delicate balances can easily be destroyed by humans with only partial knowledge of extremely complex interrelationships.

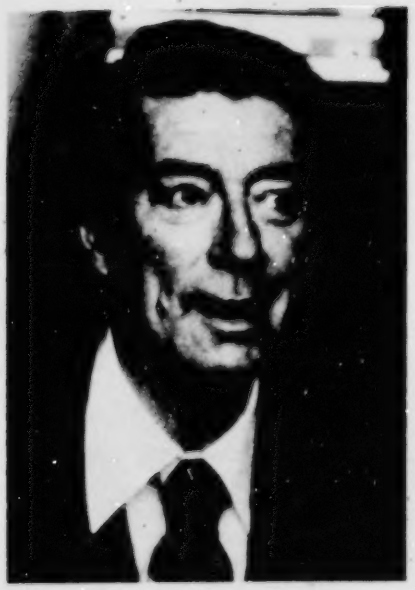
Hints of this second, or ecological, viewpoint (the "ecosystem concept") appear in antiquity, but the significant developments began in the last years of the 17th century. Its outstanding contribution is the stress on the interrelationships in nature.

In an 18th-century example, farmers killed birds because they ate the fruit in their orchards; they later regretted doing so because insects quickly multiplied. It is this concept that makes possible a deeper understanding of the effects of pollutants, plant and animal extinctions, deforestation, the use of fire, soil erosion, and other massive transformations of nature.

The mosaic pattern of the earth with its physical, biological, and human elements and the distributions of simple and complex technologies, ancient and modern, have made culture the crucial pivot in the relationship. And human cultures now give little evidence of becoming homogeneous.

On the contrary, people wish to keep their customs, traditions, religions, languages, arts and literatures. Many of these are intimately concerned with their attitudes toward their natural surroundings and to their tools, whether they are computers or digging sticks.

This means a complex worldwide diversity of attitudes both to nature and to technology. They have now become key elements in the future of the earth and of its peoples.



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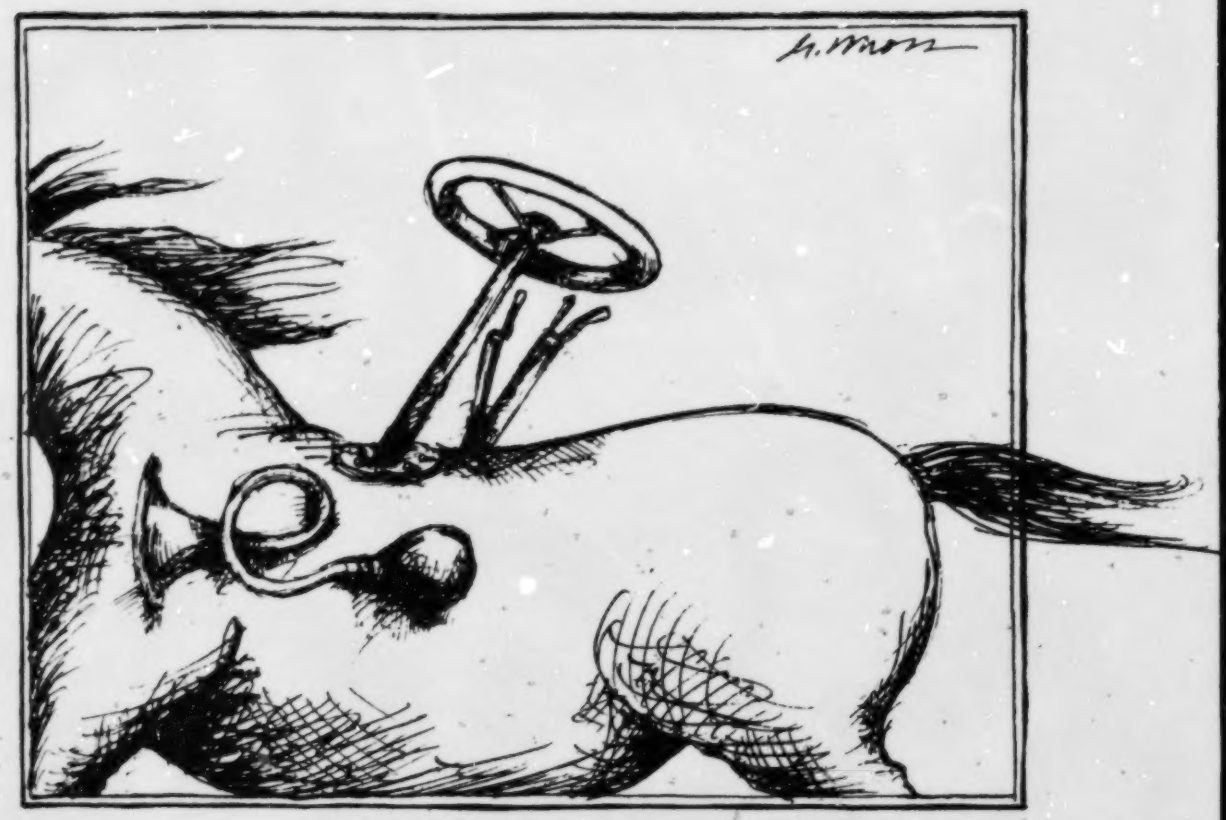
CLARENCE J. GLACKEN has been Emeritus Professor of Geography at the University of California, Berkeley, since 1976, having taught there since 1952. His 1967 book, *Traces on the Rhodian Shore*, received a citation from the Association of American Geographers. He is also the author of *The Great Loochoo: A Study of Okinawan Village Life* and of numerous articles about man and nature.



6. The Influence of Societal Values

EDWIN T. LAYTON, JR.

Henry Ford once said that purchasers of his famous Model T could have any color they wanted—so long as it was black.

Certainly technology did not force Ford to produce automobiles in only one color. This was a case where societal values influenced technology.

Ford's "Tin Lizzy" was not merely popular; it aroused deep affection. It did this precisely because it embodied many American values. The color was in keeping with a religious and cultural heritage that valued plainness.

But the Model T also reflected American democracy. Before Ford the automobile had been the plaything of the rich; after him it became available to the masses. Putting Americans behind the wheel fulfilled values nourished on the frontier: mobility, restlessness, individualism, and a conception of personal freedom that bordered on anarchy.

Ungainly as it was, the Model T nevertheless expressed an aesthetic principle that form should follow function. Perhaps the finest expression of this principle was the Clipper ship, now often considered the most beautiful of all sailing ships. It was, however, criticized on aesthetic grounds by contemporaries. John Griffiths, who invented the Clipper, defended it by arguing that beauty consisted of "fitness for the purpose, and proportion to effect the object designed."

This functionalist aesthetic, sometimes called American "vernacular," helped to give form to a vast number of things made in America. Here, too, societal values helped guide technology.

Societal values also account for the demise of the Model T. Ford's masterpiece admirably fitted the needs and values of a rural market. But urbanization and a growing taste for luxury doomed the Model T. In the 1920s, General Motors wrested automotive leadership from Ford by catering to the new public tastes, offering choices of color, models, and luxury features.

Technology and Social Change

Though technology is manifestly influenced by societal values, many people think that technology cannot be controlled.

Karl Marx was one of the first to express the idea that technology determines the course of social change. Marx argued that "the hand-mill gives you society with the feudal lord; the steam-mill gives you society with the industrial capitalist."

In this case, historical research has refuted Marx. The Doomsday census of 1086 A.D. inventoried more than 5,000 mills driven by water-power—not by hand—in England alone, at a time when the feudal lord was still very much in evidence. Conversely, we find industrial capitalists with factories driven by hand, wind, or water power before the adoption of steam.

There is no inevitable cause-and-effect relationship between technological and social change. Each advance in technology creates many new possibilities; only a few are realized by a particular society. The Amish provide an interesting example; they reject most modern technology for religious reasons.

Over the course of centuries China and the West often made strikingly different choices concerning the social uses of technology. The printing press and paper served to entrench the Mandarin establishment in China, but stimulated radical social changes in Europe. The Chinese also invented gunpowder, but used it for firecrackers; the West used it in cannon.

Social Lag

The idea that technology is out of control may result from the way we frame our questions. A useful way to understand the interaction of technology and society is through the theory of "social lag" developed by the American sociologist William F. Ogburn.

The interval between an innovation and society's adjustment is what Ogburn called "social lag." This theory emphasizes the disruptive effects of technological change and the need for mechanisms to protect society. It therefore helps us understand a good deal of recent social history.

But if we take the new technologies as "given," then social problems such as air pollution and urban decay appear to be imposed upon society by some mysterious force of technology. When we examine the sources of new technologies, however, this is clearly not the case.

The automobile, for example, is one of the most important causes of both air pollution and urban decay. But automobiles were not forced upon the public. Popular literature prior to the introduction of the Model T shows that Americans hoped for, and wanted, a cheap car for the masses. Americans saw the automobile as a way of reducing urban congestion by letting people move to green suburbs. It did just that, but it left the inner cities to decay.

Automobiles were expected to eliminate "horse pollution," no small matter. They did so, but they created a new, insidious form of air pollution, "smog." Thus the urban decay and air pollution produced by automobiles were not caused by some mysterious force of technology. They are by-products of doing something that the public clearly wanted to do. In this case technology is not out of control. Rather, we are paying a penalty for our own lack of foresight.

Social Needs

Technology does not exist for its own sake. It is the means by which society achieves certain ends. Technological activities are initiated to meet social needs.

The crucial question, then, is how are social needs determined? In America the traditional answer has

been market demand. But cheap cars, along with other things that society wanted, require very large, complex industrial organizations for their production. A compact car would cost about $50,000 if produced by hand.

As a result, free competition in the open market has been replaced by conscious control by a small number of industrial giants. The "invisible hand" of the free market has been replaced by the "visible hand" of managerial planning.

Despite the enormous concentration of power in the hands of a tiny elite, there has been little public quarrel with the criteria of choice. Americans grumbled about the big corporations, but until recently they appear to have approved of their products, if not all their practices.

The American automobile manufacturers, for example, had little difficulty "selling" the American consumer the idea of larger, heavier, more luxurious, and more powerful cars. They were more profitable to produce, and Americans seemed very pleased with their "gas guzzlers."

But increased weight required more efficient engines, which meant increasing the compression ratio, which in turn caused a large increase in the emission of nitrous oxides. Higher compression in automotive engines was the most important single cause of a staggering 628 percent increase in the rate of production of these harmful pollutants from 1946 to 1967.

Consumers' Revolt

As Ogburn might have predicted, disruptive and threatening technological changes produced a reaction from society. The auto makers' neglect of safety led Ralph Nader in 1965 to mount a crusade that broadened into a consumers' revolt. Environmentalists, following the pioneering work of Rachel Carson in 1963, had already begun their protests through such agencies as the Sierra Club.

Scientists also made an important contribution, pointing to the public dangers inherent in radioactive fall-out in the 1950s. More recently, scientists have raised serious questions concerning the safety of nuclear power.

In all of these cases the force of aroused public opinion brought government action. Perhaps the clearest case is provided by the automobile: government, responding to public pressures, is attempting to impose a new set of value priorities upon manufacturers, particularly in the areas of safety, pollution, and fuel consumption.

Behind the rancorous debates over particular issues something important is taking place. We are being forced to rethink long-accepted fundamentals. Our democratic society is attempting to redefine its values, reorder its priorities, and reshape the mechanisms through which these values guide the course of technological development.

It is too soon to predict the outcome. But one thing is clear: societal values do influence technology.

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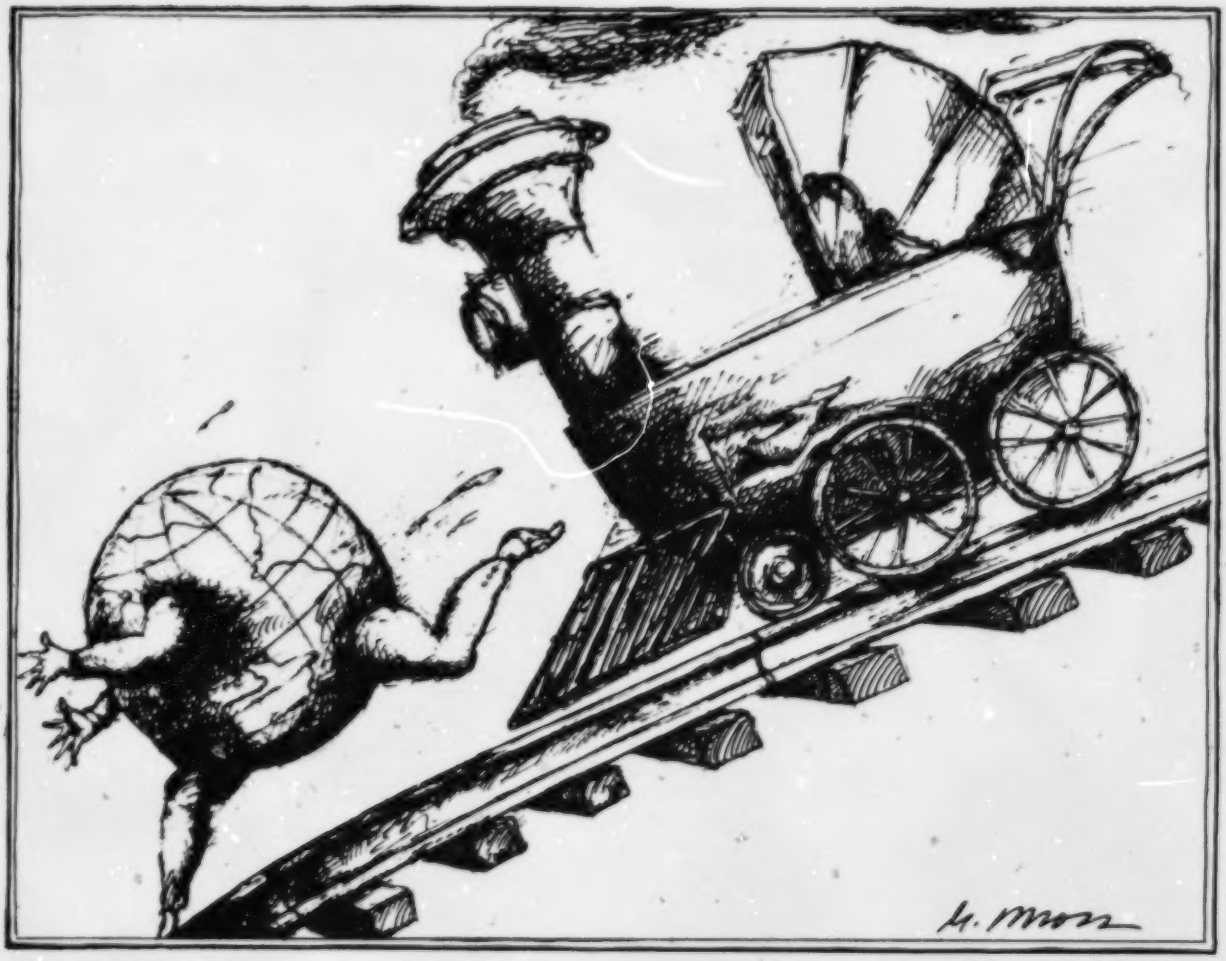

7. Technology, Population, and Resources

KINGSLEY DAVIS

Theoretically, technology gives man the unique power to determine his own fate. In practice, however, the long-run consequences are unforeseen and usually undesired.

A tragic illustration is the population crisis. Technology has made possible a formidable increase in population that now threatens to exhaust the energy resources on which the growth itself has depended. If not stopped by deliberate policy, population growth will probably be stopped in unintended, less humane ways.

During most of human existence there was no population problem. Human fertility was low because children require a long period of learning and hence dependence. Mortality, on the other hand, was substantial, partly because of warfare, predation, and occasional famine, but mainly because of parasitic and infectious diseases. Such long-run population growth as did occur was made possible by migration into new areas.

Thus, although man has existed for more than half a million years and probably numbered 50,000 some 400,000 years ago, by 8000 B.C. there were probably only about 5 million people, according to the estimates of demographer John D. Durand. The rate of increase was only one-tenth of one percent per century. (See Table 1.)

Table 1: Growth of Human Population

	Estimated Population	Percent Increase per Century
400,000 Years Ago	50,000	
10,000 Years Ago	5,000,000	0.1
A.D. 1750	791,000,000	5.2
A.D. 1979	4,285,000,000	109.1

If that rate had continued after 8000 B.C., it would have required over 700,000 years to reach the present world population—4.3 billion. Instead, it took only 10,000 years. Why?

Destroying the Balance of Births and Deaths

The answer is technology.

At first used mainly for hunting, technology was applied to agriculture and animal husbandry about 10,000 years ago. Since then, the balance between fertility and mortality has been destroyed. The improvement in production strengthened people's resistance to disease but did not, since it came too swiftly, cause fertility to adjust to reduced mortality. Between 10,000 years ago and 1750 A.D., the rate of population increase, 5.2 percent per century, was fifty times the rate before then.

The coming of industrialism dramatically reduced the death rate in two ways: first, enormous further improvements in *productive* technology strikingly improved shelter and diets, and second, the development of *medical* technology began, after about 1850, to control infectious diseases. As a result, between 1750 and 1979 the rate of global population growth was twenty-one times as fast as it had been during the preceding 10,000 years.

Yet the level of living rose simultaneously, because the harnessing of fossil energy meant seemingly unlimited productive capacity. Population growth and prosperity came to be equated.

Population Growth Today

Since 1950 the rate of population growth has remained approximately stable, around 1.9 percent per year. This is little cause for joy, however, because the rate is extremely high: it would double the population every 37 years. And, because of the enlargement of the base, that is, the greater number of people each year, the *absolute increase* continues to rise (Table 2). From 1975 to 1979 the absolute increase was 64 percent greater than it was between 1950 and 1955, although the *rate* was almost identical.

At present approximately 80 million people are being added each year!

Ironically, 79 percent of the world's population growth is occurring in the 45 percent of the world's area that is still underdeveloped, an area mostly in the tropics which is already 2½ times as densely settled as the developed regions.

The reason is that the medical knowledge that developed slowly in the industrial nations can now be transferred overnight to backward areas, causing death rates to drop about four times faster than they did from similar levels in the industrial nations. Yet the social structure has changed only slightly, and incentives for having children remain strong.

Thus the less developed countries have the highest

Table 2: Recent Increases in the World's Population

	Estimated World Population	Increase in Five Years*	
		Absolute	Percent
1950	2,526,000,000		
1955	2,770,000,000	244,000,000	9.65
1960	3,058,000,000	288,000,000	10.40
1965	3,371,000,000	314,000,000	10.25
1970	3,722,000,000	350,000,000	10.39
1975	4,100,000,000	379,000,000	10.18
1979	4,421,000,000†	401,000,000‡	9.78

*Calculated on the basis of figures less rounded than those shown in Column 1.
†Estimated by present author.
‡Adjusted to a 5-year basis.

Source: U.S. Bureau of the Census, *World Population 1977* (Washington, D.C.: 1978), pp. 14–15.

natural increase ever known. In Syria, for example, it is estimated at 4 percent per year, a rate that will double the population in less than 18 years. In Egypt, where the density on agricultural land is already unbelievable and the poverty legendary, the natural increase is 2.6 percent per year, enough to double the population in 27 years.

Technology and Resources

Fundamentally, the 5½-fold upsurge in the earth's population since 1750 rests on fossil energy. Coal, oil, and gas permitted a novel development: a simultaneous rise in population and in level of living.

In the past, productive gains were used to sustain more people rather than to raise standards. Now the use of seemingly inexhaustible energy meant that each human being could have the equivalent of dozens of servants. It meant that costly medical science could be developed and death rates around the world reduced.

But alas, the heedless consumption of energy is exhausting the earth's supply of oil and gas, forcing a new reliance on coal, the best deposits of which have been mined. Furthermore, the world's population is so huge that any satisfaction of energy demands, from whatever source, endangers the environment.

The desperate search has turned to nuclear energy, but the more complex the technology required, the more dangerous it is. The problems of uranium supply, radioactive wastes, and nuclear weapons and accidents are not easily solved. Nuclear fusion remains a costly dream likely to consume huge amounts of energy before yielding a net return some fifty to a hundred years from now.

Although predictions are uncertain, it seems probable that either the world's consumption or the world's population will have to be reduced.

Many people advocate the first alternative: returning to a simpler technology based more on muscle than on mechanical power. The world's population, however, is far beyond that possibility. Human beings are now so numerous in relation to resources that only the most advanced technology can keep them alive, much less give them a decent living.

The reason is simple: We use more energy to produce food than the food itself supplies. We are thus eating fossil energy. The countries in which half to four-fifths of the labor force is engaged in agriculture—that is, where human muscle is important in cultivation—nearly all import food from countries where mechanical energy is abundantly used. As the energy dries up, so will the food supply.

Since 1955 the world's arable land has hardly increased, while the population has risen by 60 percent. As much farm land is lost each year through erosion, urban encroachment, and desertification as is added by irrigation, drainage, and terracing. There are now approximately 789 persons in the world per square mile of arable land. Thus the huge increase in the world's food supply, paralleling the growth of population, has been due almost entirely to greater use of energy for fertilizers, irrigation, and so forth rather than expansion of agricultural land.

In the next four decades humans will doubtlessly strain every nerve to support an ever larger population. If so, it will demonstrate that the species is tool-smart but goal-stupid. No purpose is served by adding more people to an overcrowded planet.

The hope that the world's birth rate will drop to match the low death rate is forlorn, because most governments are content merely to institute "family planning" programs and hope for the best. Because of their birth rates, less developed countries have an extremely young population. Even with low fertility per woman, they will expand their population prodigiously.

The struggle for dwindling resources may cause the small wars now raging in the world to flare into a major conflagration.

If so, the frightful weapons that modern technology can create may wipe out most—or perhaps all—of the human population.

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8. Incentives for Innovation: Technology and the Economy

NATHAN ROSENBERG

Rapid and pervasive technological innovation has been primarily responsible for the long-term improvements in material well-being that have characterized western industrial societies.

But it has also been responsible for such undesirable consequences as damage to the environment and depletion of some natural resources.

The development of an effective set of policies toward the generation of new technologies—technologies that will meet our social goals—is therefore one of the highest priorities confronting our society.

Technological innovation has, of course, done more than just increase the output of goods with unchanged characteristics. Its effects are not adequately summarized in terms of so many more automobiles, bushels of wheat, or square yards of cotton textiles.

Rather, and more importantly, technological innovation over the past two centuries has dramatically transformed the composition of the economy's output as well as increasing its volume. In doing this it has also transformed our lives.

It would be an unproductive intellectual exercise even to look for 18th-century equivalents (or even the recognizable antecedents) of certain products that we take for granted today—jet airplanes, computers, plastics and synthetic fibers, vast quantities of electric power available at the touch of a switch, television, telephones, antibiotics.

Technology and Capitalism

Historically, this technological development has been very closely connected with the rise of capitalist institutions and the powerful incentives that these institutions have provided, through the profit motive, for new technologies. The point was forcefully highlighted well over a century ago by even the severest critics of capitalist society, Marx and Engels, in the *Communist Manifesto*, published in 1848:

> The bourgeoisie, during its rule of scarce one hundred years, has created more massive and more colossal productive forces than have all preceding generations together. Subjection of Nature's forces to man, machinery, application of chemistry to industry and agriculture, steam-navigation, railways, electric telegraphs, clearing of whole continents for cultivation, canalisation of rivers, whole populations conjured out of the ground—what earlier century had even a presentiment that such productive forces slumbered in the lap of social labour?

Note that Marx and Engels do not attribute this explosion in productivity to the emergence of science, or to a religious ethic, or to some new impulse to human ingenuity. They attribute it specifically to the rise of bourgeois (that is, capitalist) institutions.

In a capitalist market place, the possibilities for profit-making through the introduction of new technologies are vast. Indeed, Marx and Engels take an even stronger position: not only does a capitalist economy offer powerful incentives to innovation, it is also essential for the very survival of the entrepreneur that he innovate as rapidly as possible. As they had pointed out earlier: "The bourgeoisie cannot exist without constantly revolutionizing the instruments of production . . ."

Profit Motive

Subsequent history has lent support to this aspect of Marx's analysis of capitalism. The market economy, in which private entrepreneurs actively seek to increase their private profits, has proven to be immensely effective in mobilizing inventive and innovative talent.

At the same time, the market economy has strongly shaped the direction of technological innovation as well as its rapid rate.

Unfortunately, the profit motive has not always worked to advance society's interests. Consequently, the goverment has supplemented the operation of the market place with public institutions or financial support for specific kinds of activities. These include agricultural experiment stations and a wide range of public subsidies to basic scientific research, from which private profits are not readily available and for which market incentives alone are therefore insufficient.

Additionally, we have become increasingly concerned in recent years with aspects of the innovative process to which we were surprisingly indifferent in the past. New technologies often inflict certain costs upon their natural and human environment that deserve to be recognized in any social accounting but are not ordinarily part of private profit accounting. These include environmental pollution in a variety of forms and safety and health hazards to workers and consumers.

New Policies

We urgently need new public policies that will offer incentives for innovation and at the same time protect us against some of the undesirable side effects of technology. Developing such policies will call for political courage and leadership as well as social imagination. The task of reconciling conflicting group interests and priorities without, at the same time, dulling or even destroying the incentive mechanisms underlying technological innovation, will be an extremely delicate undertaking.

Large issues are at stake. History makes it clear that private business is strongly influenced by market forces concerning the direction as well as the pace of inventive activity.

Thus, for example, the abundance of forest lands and the cheapness of forest products in colonial America (and later) led to the invention of a vast array of ingenious technologies for exploiting wood. The abundance of good farmland in the American mid-west in the 19th century generated an incredible profusion of ma-

chines enabling a single farmer to cultivate a far larger acreage than his European counterpart. And the exhaustion of high quality mineral deposits in the 20th century has already prompted the development of techniques for exploiting low quality ores that were previously neglected.

Shaping Technology

Our history also shows us that technology is extremely versatile and that it is highly responsive to changes in incentives and rewards. It should not be beyond our ingenuity to use the incentives of the market place to develop new technologies that will deal much more effectively with such current concerns as environment and energy.

It is hardly surprising, for example, that private enterprise developed technologies that fouled the air and treated watercourses as open sewers for the effluents when no cost was imposed upon them for doing so. On the other hand, we can confidently predict that a system of taxes or other charges for industrial activities that pollute the environment will eventually lead to the development of new technologies that produce far less pollution. Indeed, in many industries far less polluting technologies are already emerging.

It is a mistake to regard technology as simply constituting part of the problem, although that has undoubtedly sometimes been the case in the past. Technology is an extremely powerful force whose shape and thrust can be influenced to a far greater extent than is generally recognized. But we cannot shape technology if we reject or straitjacket it, as has been increasingly the case with some of the regulatory activities of government in recent years.

Rather, we should seek ways of increasing the rewards for technological innovations of the kind that we regard as socially desirable. Prizes, patent grants, and favorable tax treatment are some of the mechanisms devised in the past to encourage innovation.

By strengthening such incentives and developing new ones, we can assure that technology will, in the future, be more consistently arrayed on the side of the solutions rather than on the side of the problems.

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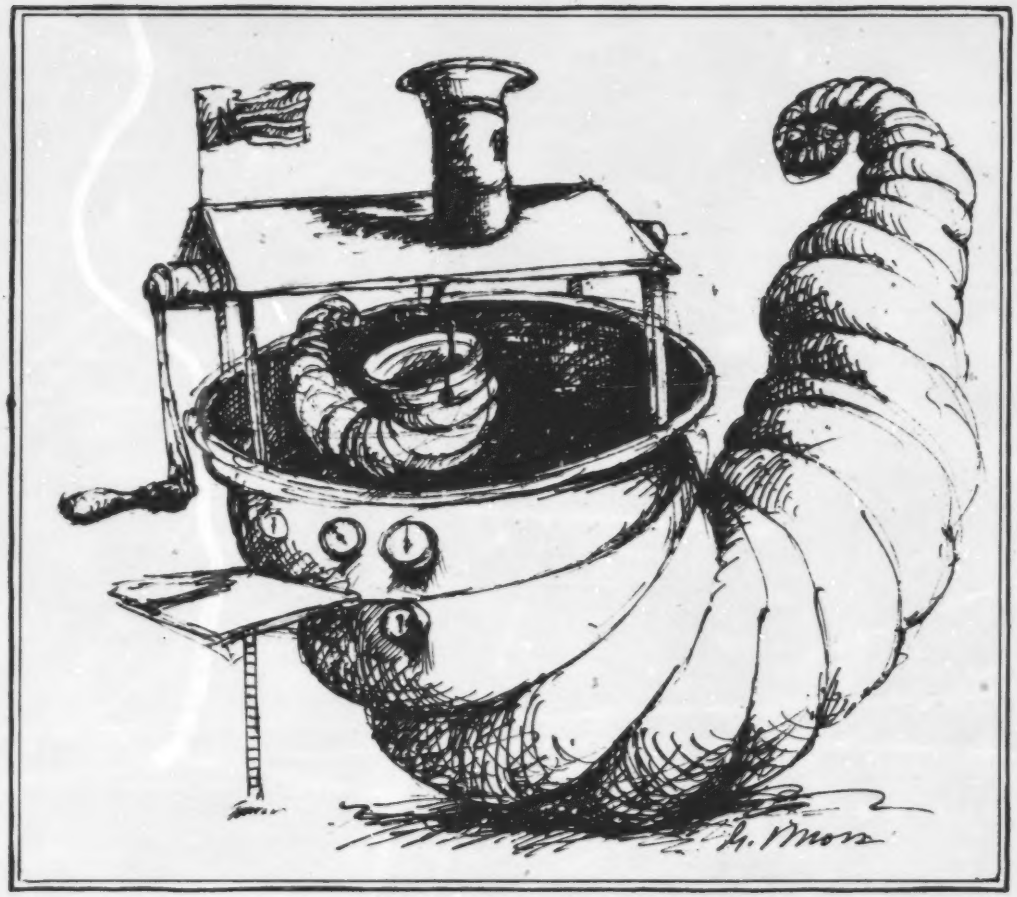

9. Science and Technology

ROBERT P. MULTHAUF

Although scientists and technologists still think of themselves as doing different things—the former exploring nature's mysteries, the latter satisfying human needs—they have come to recognize their increasing interdependence, and many people today have trouble distinguishing between them.

To the 19th-century American, the puttering of "pure" scientists seemed in ridiculous contrast to the ever more fruitful business of inventors.

A century before, Benjamin Franklin, a distinguished practitioner of both science and technology, favored science, but he was remembered mainly as a political hero. Joseph Henry, probably the most important American scientist of the mid-19th century, also practiced both, and clearly preferred science. He deplored the American mania for novelty and, as first Secretary of the Smithsonian Institution, convinced Congress to establish in the Smithsonian the nation's first scientific research laboratory.

But science was dull stuff compared to the inventor's apparently inexhaustible bag of tricks. Before 1850 the inventor turned out such wonders as the cotton gin, patent leather, the harvesting machine, clipper ship, Colt revolver, and mass-produced clocks and guns.

A Genius for Invention

Europeans began to suspect that Americans had a peculiar genius for invention. By the 1880s they were convinced of it by the inventions of Thomas Alva Edison, who was entertained as an equal by the greatest scientist of France, Louis Pasteur.

Edison called himself an inventor, and was as emphatic about it as Henry had been in calling himself a scientist. Like Franklin before them, Henry and Edison worked in electricity, a field that changed in Franklin's youth from a collection of lore about sparks and "attractions" into a new science.

But even while electricity remained largely a mystery, it was readily exploited by inventors. Always alert for utility, Franklin supplemented his science by inventing a toy electric machine that turned a wheel. In the 19th century, such electrical toys evolved into practical machines. Edison combined the steam driven generator with the electric light and a distribution system to inaugurate the modern era of electric power.

By the 1880s the cornucopia of technology had yielded artificial plastics, aluminum, the calculating machine, typewriter, and machine gun.

But the most startling inventions were still in electricity, where Americans remained preeminent. The electromagnetic telegraph had cut the time for communicating between cities and countries from days to seconds. The most successful was that of Samuel F. B. Morse, a painter who knew little of electricity, but who had an indispensable idea, the "Morse code." Morse consulted Henry, whose annoyance at this exploitation of his favorite science increased when Morse utilized one of Henry's incidental inventions, the electromagnetic relay.

Henry's indignation had scarcely subsided when he was visited by a teacher of speech named Alexander Graham Bell, who wanted to transmit speech by electricity but admitted knowing nothing about electricity. Henry's gruff advice that he "learn it" masked a willingness to help, and Bell became in 1878 the most successful of numerous inventors of the telephone.

Eminent Mechanics

American inventiveness was, in fact, a culmination of events that began in Europe in the Middle Ages, when nonhuman sources of power first mechanized metal working and textile production. Anonymous craftsmen in Italy and Germany were mainly responsible for these innovations, but by the 18th century Britain had taken the lead, with the invention of the steam engine and its development into a versatile source of power for factories, railroads, and steamships.

These inventors were no longer anonymous laborers in the vineyard of technology. James Watt, Henry Maudslay, and other "eminent mechanics" were predecessors of 19th-century American inventors.

These events paralleled a revival of the rational explanation of nature which we call science—a more visible development since it involved educated upper and middle class men such as René Descartes, Christian Huygens, and Isaac Newton. Science also became a hobby of the wealthy, thanks largely to new instruments, such as the telescope and microscope.

There was no gulf between science and technology in the 17th century. Scientists agreed with the English philosopher Francis Bacon that science should be applied to the useful arts, and many scientists tried their own hands at invention.

The scientist-inventor, however, proved to be a dud. Science and technology seemed, in the last analysis, to require different kinds of talent. In time the European scientist decided to stick to his specialty, which was, after all, more intellectual, less commercial, and clearly a higher calling. "Eminent mechanics" were still mechanics, beneath the level of what came to be called pure science.

In the United States this bias was reversed. Democracy was the ideal, and "monarchical institutions" such as academies of science were rejected. The eminent mechanic was honored in America both socially and economically.

Thus Franklin, Henry, and Edison represent phases in the relationship of science and technology. Franklin was intellectually a European, a scientist-inventor imbued with Baconian ideas. Henry was a scientist in an America where scientists were held in low esteem. Edison was a technologist in an America where the eminent mechanic reigned unchallenged.

Useful Science

But other phases were to follow. Even as Edison enjoyed his triumph, Bacon's long disregarded assumption that science could be useful to technology was becoming a reality.

In 1856, A. W. von Hofmann, a German who headed the Royal College of Chemistry in London, was appalled when his student, William Henry Perkin, tried to salvage an unsuccessful experiment that yielded a messy purple sediment by marketing the stuff as a dye. It was the first of many artificial dyes that were commercially profitable, and eventually scientifically interesting.

By the 1870s the production of dyes had become too complicated for the uneducated and required the special knowledge of the scientist. Only Germany possessed many such chemists and by 1900 enjoyed a near monopoly on artificial dyes.

By the 1920s others began to imitate the Germans, and the chemical industry everywhere came to be dominated by chemists holding university degrees.

In other fields the eminent mechanic held on for a time, but one industry after another has fallen under the shadow of academic science. Edison lived to see this happen in his own field. Electricity had continued, through the invention of radio, to reward the uneducated genius. But by the 1920s the electrical engineer was finding mathematics and physics unavoidable, and the eminent mechanic found himself an outsider.

In one of his last interviews, Edison predicted that man would invent a weapon so horrible that he would "abandon war forever." Such a weapon was indeed developed, not under the leadership of eminent mechanics but of university trained scientists and engineers.

Scientists and engineers have found a psychologically acceptable middle ground in "applied science," while military necessity and government support enable them to produce marvels far beyond the capacity, if not the imagination, of the now legendary Edison.

Since 1945 science and technology have become virtually indistinguishable, except as preferences of particular individuals. "Improvements" have gushed forth across the whole spectrum of science and technology, and Francis Bacon has been justified.

The late 20th-century American no longer laughs at science, while his enthusiasm for technology has dimmed considerably, and he has increasing difficulty telling which is which.

It seems that we have entered not just another phase in the relationship between science and technology, but another era, with a different question: the relationship between science-technology and society.

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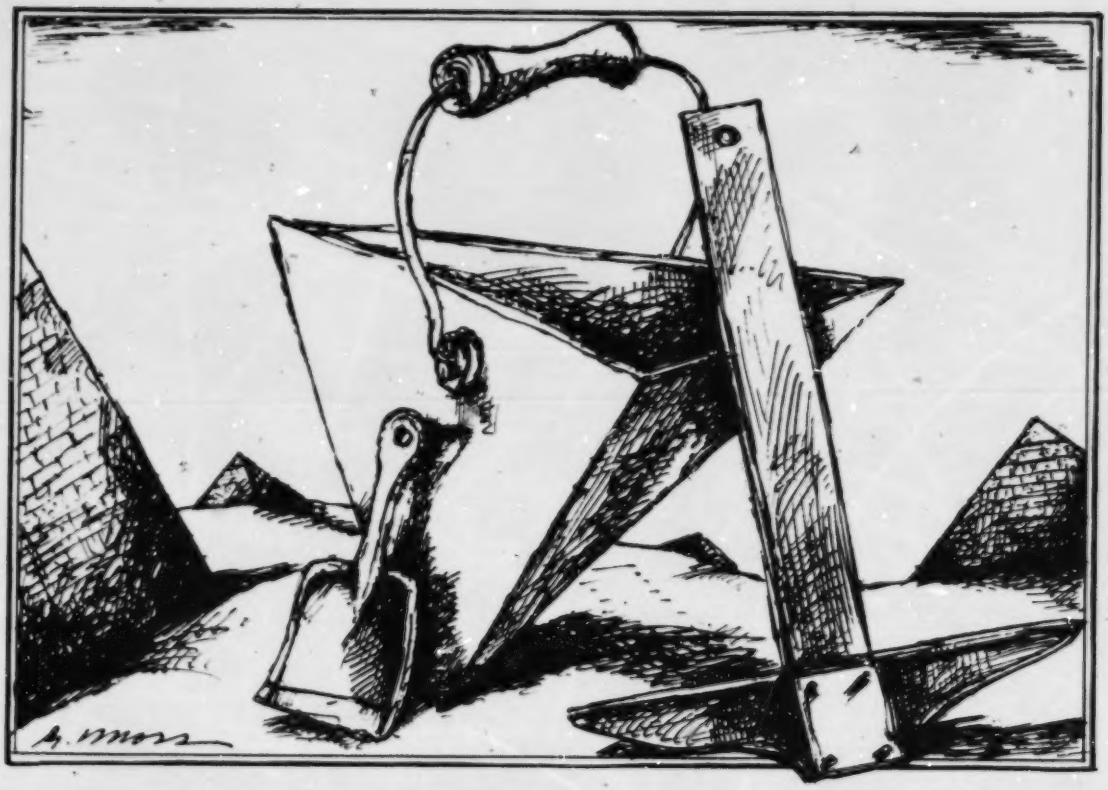

10. The Imperatives of Engineering

EUGENE S. FERGUSON

Engineers have a greater effect on the kind of world we will live in than most of us recognize. Less than one American in a hundred is an engineer, but because they are decision-makers, engineers are far more influential than their numbers suggest.

Many engineers deny this influence, insisting that they merely carry out the instructions of others—of politicians, for example. Yet in fact, engineers write a politician's shopping list by furnishing alternative solutions to particular problems—solutions that require engineers to carry them out!

Most of us highly approve of the world our engineers have built for us. Yet some of us become angry and frustrated when technical systems often seem to demand that we adapt to the system's needs, rather than the other way around.

To understand why technical considerations in engineering projects tend to submerge social or human needs, we must examine the controlling principles, or imperatives, that shape the way engineers think. Engineering imperatives are often more powerful than the needs and wants of whose who use what engineers design.

An engineer (1) strives for efficiency, (2) designs labor-saving systems, (3) tries to design the control of a system into it, so the user will have limited choices.

The engineer is also fascinated by his or her ability to disregard human scale, so he (4) favors the very large, the very powerful, and (in the electronic revolution) the very small.

Finally, because an engineering problem is inherently interesting, (5) it becomes an end in itself, rather than a means to satisfy a human need.

Let us consider these imperatives.

Efficiency

(1) Efficiency comes easily to the technical mind, even though it is one of the slipperiest words in our language. High efficiency means high output for a given input. For example, if a quantity of fuel is the given input to an automobile engine, the power output from a diesel engine will be the highest; from a conventional gas engine one-third less; and from a gas-turbine engine, one-half that of the gasoline engine.

"Efficiency" as used in engineering also has a rhetorical meaning. It may mean "more powerful" or "better performance." When an engineer seeks efficiency, his ideal is flexible—enabling him to think of a machine or system that performs the way he thinks best (high torque, satisfying roar, whatever) as "most efficient." Gas turbines have their advocates, and most engineers continue to choose gasoline engines over diesels.

Labor-Saving Systems

(2) Labor-saving systems are generally preferred by engineers, with no serious thought given to alternative possibilities. Thus, machines are being developed in agricultural experiment stations to eliminate workers, particularly in harvesting fruits and vegetables. The consequent drift of displaced farm workers to city slums is not seen by engineers as part of the problem.

Many engineers believe that labor-saving without limit is a positive and unquestionable good.

In 1916, for example, the president of A. O. Smith Corporation, a maker of automobile frames, sought to build a "plant that would run without men."

Bankers advised against spending money on so costly and uncertain a goal, but company president L. J. Smith and his engineers worked doggedly to build an automated factory of unprecedented mechanical complexity.

Ten years and several million dollars later, Smith proudly unveiled a vast machine that turned out a thousand automobile frames per hour. It required so few men to tend it that the labor cost per frame was less than 25 cents! The plant was a marvel of the particular "efficiency" that obsessed Smith, which was to eliminate all workers.

Built-in Controls

(3) Control is an imperative that guides the design of systems such as an assembly line and the new Metro subway in Washington, D.C.

Engineers decide who will do what on an assembly line. Subdividing work into minute tasks that require mere dexterity and minimum training and skill goes back 200 years to the French pin-makers who supplied Adam Smith with his often-quoted example of the division of labor. Drawing the wire to proper size, straightening it, cutting it to length, forming the head—each was assigned to a different worker.

The assembly line was brought to its logical extreme by Henry Ford in 1914. It took charge of both a worker's time and his sense of timing. The assembly line moved inexorably, dragging work along on a chain, and pacing the workers. Aside from doing as told (efficiency engineers called it "cooperation"), the worker had no opportunity to use choice or judgment.

Paradoxically, designing an assembly line provides an absorbing challenge to the engineer who decides how work will be subdivided. In so doing, he reduces to a minimum the mental effort required of people who spend their working lives on the line.

Washington's new Metro subway is operated by computerized controls, but Metro yielded to public pressure and put an attendant at the head end of each train. On a recent trip on the Metro, I noticed that the head of the train stopped automatically at the center of each station platform. After a delay, the human being in the front car regained control momentarily and inched the train forward to the proper position.

Difficulties with the Metro train operations pale, however, before the nightmare of the fare-card system. A

magnetically coded card is purchased from a machine, shoved into a slot to gain admittance and into another slot for departure from the station. The record of broken-down card dispensers and unresponsive turnstiles has forced management to admit that its fare-card system is its "Achilles' heel."

But rather than replace the system with responsive persons, the next move (in stereotyped phrases of management) is to redesign the system to make it "more efficient."

Nonhuman Scale

(4) The urge to transcend human scale is as old as engineering. Some famous structures whose builders were guided by this imperative include the Egyptian and Mexican pyramids, the enigmatic statues on Easter Island, and the Eiffel Tower.

Since 1957 and Sputnik, a new imperative has been added: Space vehicles requiring small, light, extremely complex instruments pushed engineers toward miniaturization of electronic computers and instruments. Small and large, the imperative of nonhuman scale is powerful.

Ends and Means

(5) Despite their frequent disclaimers of emotional involvement in the work they do, engineers are conscientious workers and can hardly escape the inherent interest of the problems with which they are concerned. Engineers' devotion to their work helps explain why so much engineering is so good, and changes and innovations so frequent and ingenious.

When an engineering project goes sour from a social standpoint, the trouble is often in the engineer's absorption in the technical aspects of the project and his forgetting or misjudging the human dimensions.

Yet it is precisely these human aspects that have become of concern. Instead of massive, centrally controlled systems, some of us are now calling for simpler solutions on a human scale. We want to see more solutions that fit the problems.

Social problems can have social solutions, which usually require discussion and compromise. Unless we insist on this, we can expect technological solutions to all problems because they are easiest to devise.

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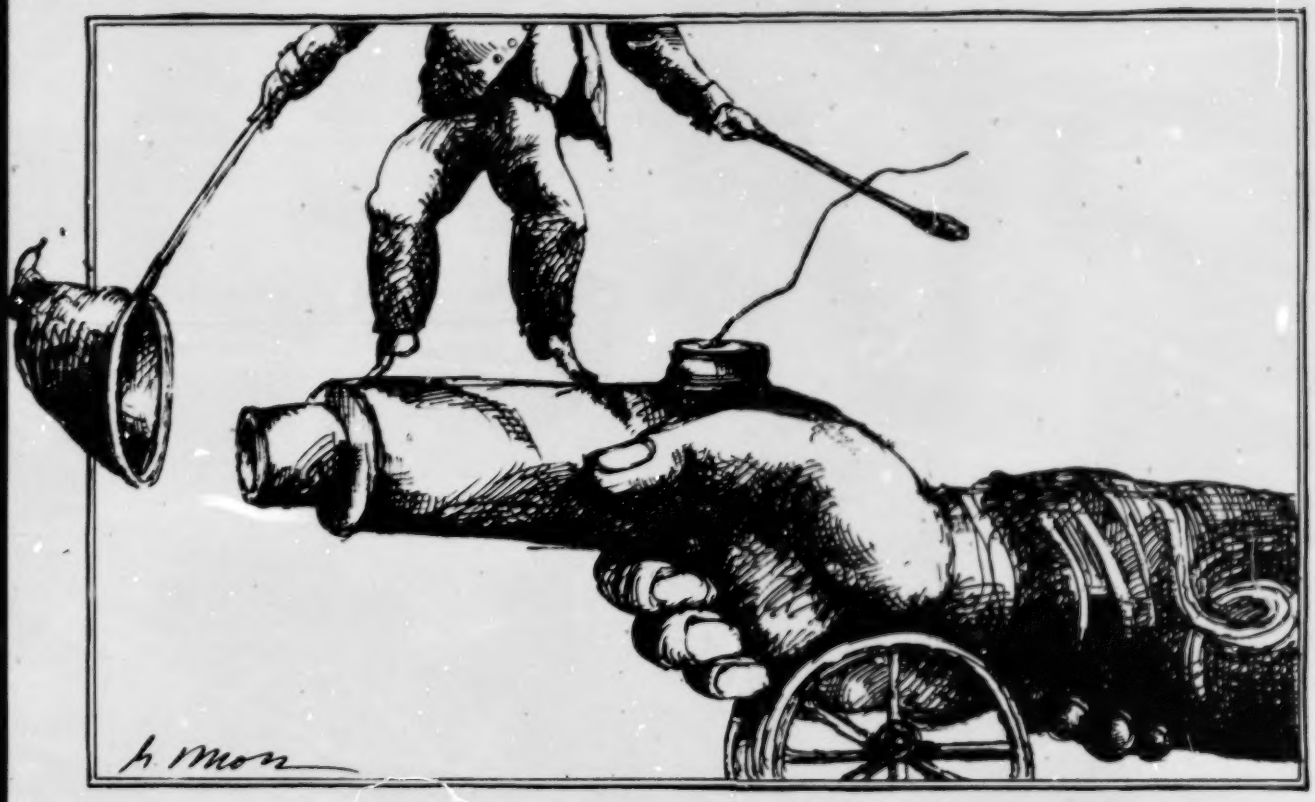

11. Wars: Hot and Cold

HERBERT F. YORK and G. ALLEN GREB

For more than three decades now, we have lived under the threat of a nuclear holocaust. But the relationship between national security and technology did not emerge with the nuclear age.

From the time that one group of prehistoric men first used clubs and spears to force their will on another group, war and technology have been closely interrelated.

And throughout history, political and military leaders on the one hand have used science and technology to further their ends, and scientists and engineers on the other have exploited the special interests of the state to advance their own goals.

In recent years, and throughout the world, such interaction between scientists and policymakers has greatly increased. Traditionally, this partnership has employed technology to produce ever deadlier weapons. But today, advanced technology can also provide the means for arms control.

The continuing partnership between government and science seems assured; how that partnership will be used is less certain.

Escalation

From earliest times until the present, new offensive technologies have always been countered by defensive developments or more powerful offensive systems. Thus, technology has produced a steady progression of more efficient instruments of death and destruction: swords, longbows, firearms, aircraft, atomic bombs, missiles.

During World War II, for example, the Germans launched a successful blitzkrieg against most of the nations of central and western Europe. They came close to overrunning Britain and Russia as well by exploiting the latest technological developments in aircraft, tanks, and related equipment.

In the West, the British stopped the Nazi advance by making full use of another new technology, radar.

German technology, in the form of modern submarines and torpedoes, almost cut off American supplies from Europe. American technology, in the form of antisubmarine warfare and intelligence techniques, reversed that process.

And, perhaps most dramatic and politically portentous of all, World War II ended with the nuclear attacks on Hiroshima and Nagasaki.

New Role for Scientists

During that conflagration, moreover, scientists and engineers did not simply respond to requests from military authorities. Rather, they became full participants in the planning process. They not only invented and built weapons, but they shared in making the decisions about which ones were needed, and even how they should be used.

Special new institutions, both inside and outside the government, had to be created to make this interaction work effectively. Such institutions have continued to evolve and proliferate since then.

Current versions include so-called "think tanks," such as RAND and other private research institutes; university operated institutions, such as the University of California's two nuclear weapons laboratories and MIT's Lincoln Lab; and permanent government committees composed of both academic and industrial scientists and engineers, which provide input on all matters from weapons development and deployment to arms control and disarmament.

Weapons Development

The Cold War and the wars in Korea and Vietnam caused these new relationships to continue long after World War II. Whenever there seemed to be a lull in the process, an event like the Russian launching of Sputnik came along to reinforce this political and scientific collaboration.

One major result of this further interaction of science and technology with national security needs was the invention of the hydrogen bomb—in its first version, 1000 times as powerful as its predecessor, the A-bomb—and the spread of both types of nuclear weapons to Russia, Britain, France, and China.

Another very significant result was the further development of rockets, which had been invented a thousand years earlier in a simple form, into huge and powerful devices capable of delivering nuclear weapons to within a few hundred feet of any specified point on the globe in a half hour.

The possession of some thousands of such weapons, in several different forms, by both the U.S.A. and the U.S.S.R. has defined the relationship of the two superpowers for the last two decades. It largely explains, moreover, why these nations occupy the positions of world power and influence that they do.

Policy Options

Throughout the post–World War II period, scientists and engineers have continued to be full partners with state authorities, participating at all levels of government, from the President's Office down, in determining what should be done as well as how to do it.

Some of these participants have placed special emphasis on our exploiting the possibilities inherent in the latest scientific discoveries before some potential enemy does. Edward Teller, commonly known as the "father of the H-bomb," and the late Wernher von Braun, a leading developer of large rockets both in Germany before World War II and in America afterwards, are two well known examples from a large group of such people.

Each of these scientists testified many times before

congressional committees; each served as advisers to Presidents, Secretaries of Defense, and other leaders; each served on many special committees; and each made countless public appearances in support of their views.

Working in a similar fashion, others have promoted the use of modern science for some military applications but have opposed other applications that they considered to be especially dangerous. In short, they became not only developers of arms, but advocates of arms control.

One prominent example is Robert Oppenheimer, who led in the development of the A-bomb but who opposed development of the H-bomb. Others are James Killian and George Kistiakowsky, who served as science advisers to President Eisenhower during the missile gap crisis but who also have become leading advocates of nuclear arms control.

Arms Development and Arms Control

Today, the interactions between scientists and government are continuing along two main lines: first, the development of more sophisticated weaponry and, second, the pursuit of political agreements to stop or at least moderate such developments.

Vietnam, the first war in which technological superiority did not work to the advantage of a state, demonstrated the need to control weapons so deadly that nations are literally afraid to use them.

The development of nuclear weapons and long range delivery systems continues: the recent advances in microprocessors and other computers are making these and other weapons much "smarter" (and more devilish); and we are hearing talk that laser beams and other so-called death rays are somewhere around the corner.

In the case of arms control and disarmament, some treaties have been worked out placing modest limits on the development of some weapons and limiting the deployment and use of certain others. The Strategic Arms Limitation Talks (SALT) are now attempting to extend these treaties, but the outlook for significant new agreements is mixed.

Advanced technology plays a key role in arms control as well as in arms development. The principal means for determining whether the various parties are complying with existing arms control treaties involves the use of very sophisticated devices. Satellites, for example, monitor both missile deployment and missile development, and very modern seismic detectors coupled with the latest data processing techniques make it possible to observe nuclear explosions from great distances.

The ever-increasing complexity of both weapons development and efforts to control these devices thus guarantees the continued partnership of government and science in the technological process. How this partnership will ultimately influence society as a whole remains perhaps the most perplexing problem facing mankind.

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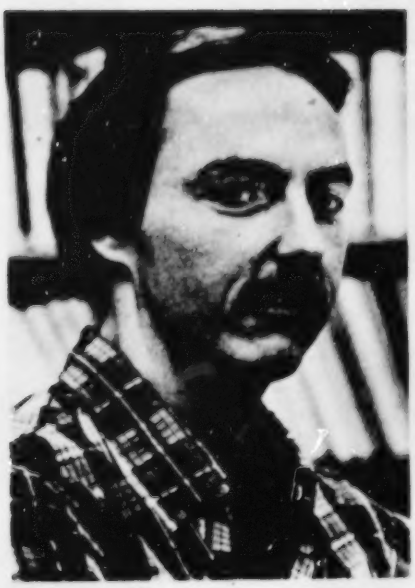
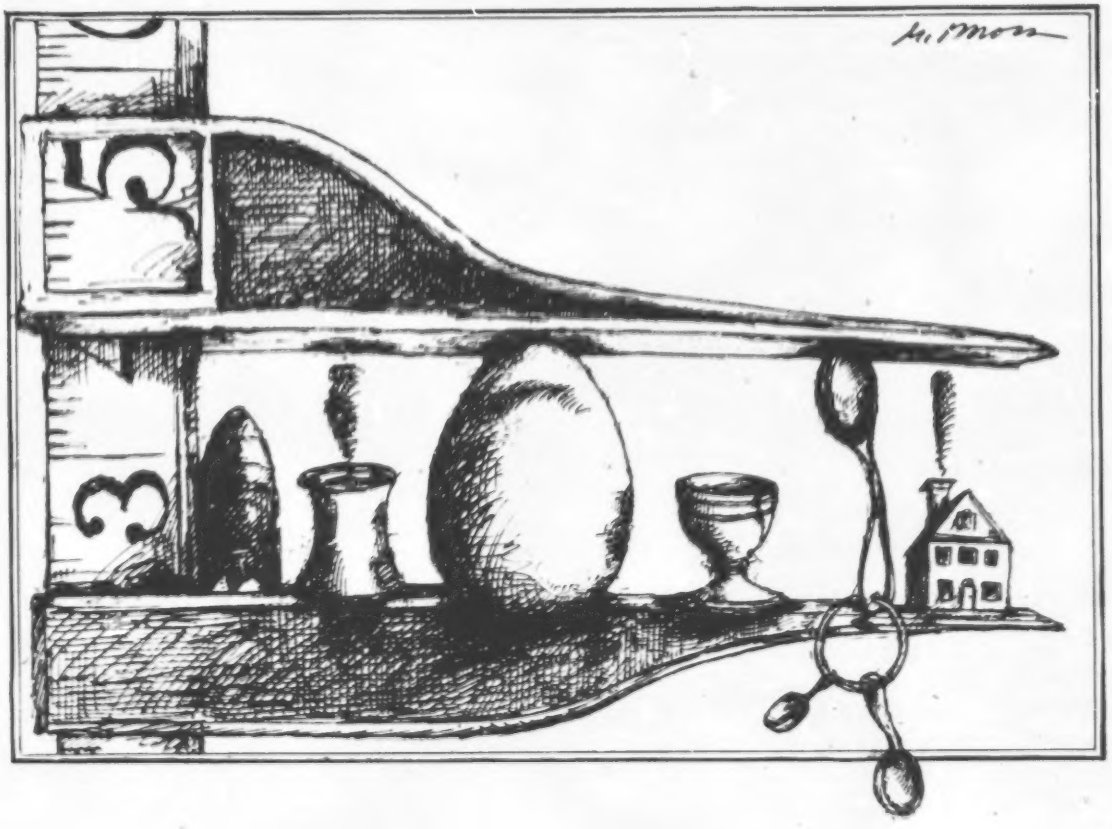


G. ALLEN GREB is research historian in the Program in Science, Technology and Public Affairs at the University of California, San Diego, where he earned his Ph.D. He is the author of an article on the Panama Canal and coauthor, with Herbert York, of articles on strategic reconnaissance and on postwar military research and development.



12. The Government's Role in Technological Change

A. HUNTER DUPREE

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Last year the U.S. government spent more than $25 billion on scientific research and technological development.

Slightly less than half this amount was spent on defense research, generally recognized as a legitimate function of all governments. But what about the rest?

Why should the government of a nation that has traditionally been committed to the concept of free enterprise be pouring billions of dollars annually into research and development?

Until the 19th century, government involvement with technology grew very slowly. It then became apparent that modern science through technology could effect rapid—and, it was hoped, beneficial—social change.

The crises of the 20th century, particularly World War II, stimulated an even closer relationship and an even greater interaction between government and technology.

Critics now charge that government is controlling the direction of scientific research and the course of technological development and that this influence is corrupting both.

Proponents, however, argue that even more government involvement is necessary to support the research and development required to maintain our standard of living and to help the poorer nations of the world.

Early Involvement

The connection between government and technology is not necessarily close. Throughout much of history, government has been the special concern of the powerful. Technology, on the other hand, very early became the special concern of craftspeople—often of humble origins but with skills that made possible weaving, pottery, metalworking, building of shelter, and all the other processes necessary to provide for human needs.

Since people specialized in certain crafts and then exchanged their products for those of others, questions of the value of weights and measures arose. Thus, more than 2500 years ago governments became referees in setting the standards of weights and measures.

Also, since money came to be measured by the weight of gold or silver, governments not only made coins but insured their value by imprinting them with official seals and by milling the edges to prevent clipping.

In the same way governments established standard measures of volume for grain and liquids, standard weights, and standard rulers of length. The power of government guaranteed the integrity of these measures used in technology. Governments still perform these functions through their mints and their national bureaus of standards.

The Nation State and Technology

In western Europe in the later Middle Ages, technologies arose capable not only of building Gothic cathedrals but also of sustaining cities and trading with Asia. At the same time, the national governments of France, Spain, Portugal, and England came into existence.

By the end of the 15th century, this combination of technology and nation states made possible the extension of trade and colonization to the Western Hemisphere.

The governments of these nations did not create the technology of the sailing ship that made this expansion possible. But they were called upon to provide support to shipmasters and sailors of a kind beyond the resources of private individuals.

This support included the development of mapmaking and the astronomical observations necessary for a reliable worldwide navigation system. By the 17th century, for example, such great institutions as the Royal Observatory at Greenwich, England, had been founded to develop astronomical charts for navigators. Governments continue to provide such services as mapmaking today.

Since traders and colonizers rarely had the time and energy to explore unknown territory, governments gradually took on the function. By the 18th century these expeditions, for example, those sent to the Pacific by the British Admiralty under Captain James Cook, had penetrated to most parts of the globe. Today, governments continue to send out exploring expeditions—to Antarctica and even to the moon.

Government Research and Technology

During the 19th century, as natural science took on its modern form, the governments of western Europe and the United States realized that they could help their people develop more powerful technology if they provided scientific research which was beyond the means of universities and other private institutions.

Despite some opposition to "impractical" research, governments increasingly concluded that the best way to attack the human scourges of scarcity and disease was to support laboratories for the production of seemingly "useless" knowledge. Hence, through agencies such as the U.S. Department of Agriculture, governments began to shift from a passive to an active attack on human problems by supporting basic scientific research.

World War II and After

The most important shift in the government's relation to science came at the outbreak of World War II. Wartime leaders saw the need to mobilize all the nation's scientific resources that were applicable to weapons and medicine.

Instead of just strengthening government laboratories, they turned to the universities, industry, and private foundations to find the laboratory facilities and the scientists, especially in medicine, electronics, and

atomic energy, whose research might mean the difference between victory and defeat.

The network of contracts which they set up carried government money out to the scientists and laboratories, resulting in such discoveries as penicillin, the atomic bomb, and radar.

At the end of World War II, government and science leaders agreed that the system of contracts tying together the universities, industry, and the foundations with government support should become permanent. The government made a definite commitment to maintain America's role as the world's leader in science and technology.

By the mid-1960s some $16 billion of government money was flowing into research and development. Every branch of technology was affected in some way. The National Science Foundation, the Atomic Energy Commission, the National Aeronautics and Space Administration, and much-expanded National Institutes of Health became the dominant research agencies of the U.S. Government.

This new trend stimulated controversy. Opponents claimed that university scientists, in order to receive government grants, were forced to pursue research in specified areas. Others charged that some programs were wasteful; the manned lunar landing program, for example, was criticized as being political and not justifiable on any scientific grounds.

Such criticisms resulted in a new emphasis on research concerned with pressing national needs, that is, projects that would visibly benefit the general public, such as cancer research.

The Need for Reassessment

In the past 15 years, a whole new series of issues developed that increased government involvement with technology.

The very success of modern chemistry and physics in industry produced pollutants that themselves became a threat. Scientific, machine-based agriculture triggered large migrations of people and transformed the inner districts of large cities. Atomic energy eased the pressure on scarce fossil fuels, but created new safety and waste-disposal problems.

Although government regulation of technology to combat the worst abuses of environment dates back to the late 19th century, active research on an unprecedented scale was clearly needed. Congress responded by setting up an Environmental Protection Agency, by changing the Atomic Energy Commission into a Department of Energy and a Nuclear Regulatory Commission, and by creating an Office of Technology Assessment.

But these actions did not silence critics of the burgeoning relation between government and technology. The federal government's encouragement of nuclear power, for example, was seen as a threat to the health and safety of people, and the accident at the nuclear plant at Three Mile Island confirmed these fears. Government policies relating to the environment, consumer products, and worker safety have also been challenged as unresponsive to public needs and wishes.

Such controversies will undoubtedly continue as long as the majority of our citizens are committed to a society characterized by high technology, which only the government can support.

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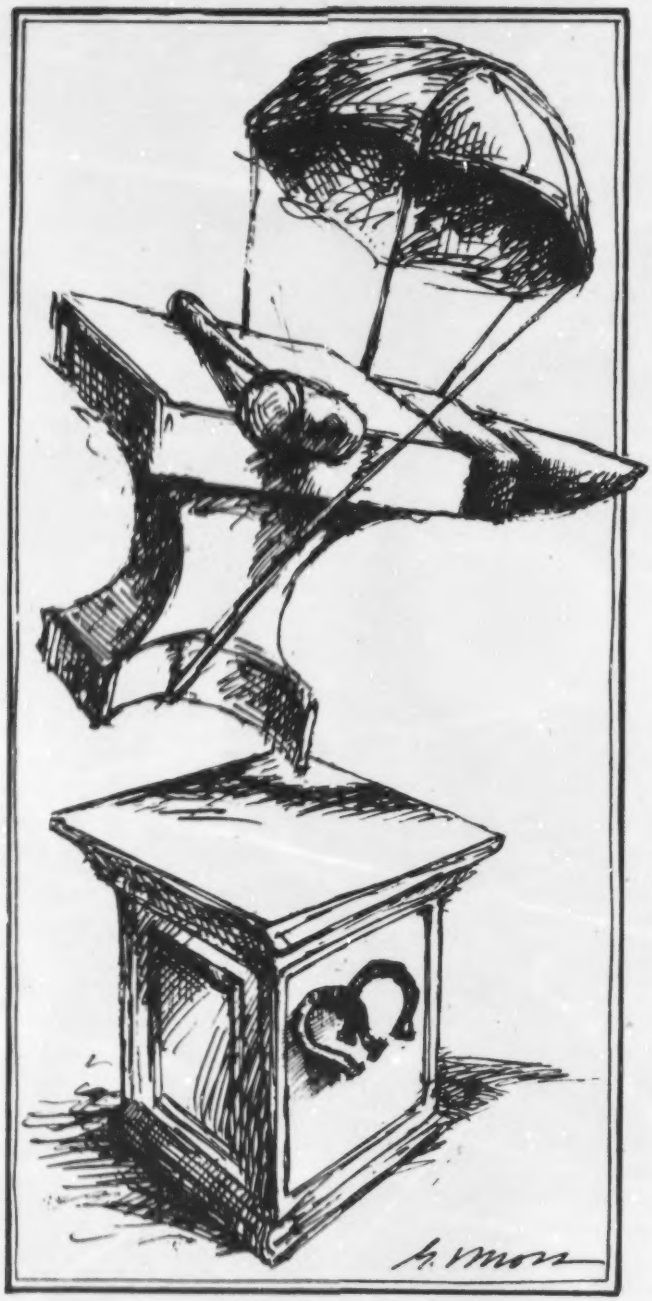

13. The Mystery of Inventiveness

LYNN WHITE, JR.

How the minds of inventors work is a puzzling problem. Why people invent what they do, when they do, remains a mystery.

Indeed, there may be no such single thing as "the innovative process." A study of a number of different inventions shows that a variety of factors enters into technological creativity. Most inventions, however, result from systematic attempts to solve specific problems.

Take the horseshoe. The world should be full of monuments to the unknown genius who first nailed iron shoes to the feet of a horse.

For nearly 3000 years after its domestication, the horse was used in warfare and sport, but only for fairly light hauling—for example, of chariots. One difficulty arose because the yoke-harness was transferred from oxen, to which it was well adapted, to horses, on which it was very inefficient for reasons of anatomy.

At last, about A.D. 800, a new harness, consisting of a rigid horse collar connected to the wagon by traces, appeared in Europe, perhaps having come from Central Asia. Without adding cost, it increased the pulling capacity of a team of horses by four or five times.

But another problem had to be solved before the new harness could become really effective. In moist regions like northern Europe, the hoofs of horses are much more fragile than those of oxen. They break easily and wear down quickly with hard usage.

Our inventor, doubtless a blacksmith who lived in northern Europe during the late ninth century, was probably familiar with the iron sandals that ancient veterinarians wired to broken hoofs to help their healing. But he also knew that these often worked loose and chafed the horse's feet.

He had a sudden, breakthrough, idea: to reduce wear and breakage, he would *nail* iron shoes to the hoofs! It was a bold, even foolhardy, notion. Horses were valuable, and to lame one deliberately would certainly have been a crime in his society. But he hammered on those shoes and they worked.

About A.D. 900 nailed horseshoes began to spread swiftly on the plains from the Atlantic into central Siberia. The importance of horses in the medieval and early modern development of agriculture, transport, and early industrialization is indicated by the fact that even today, when horses are used mainly for sport, the standard measure for the work-capacity of any engine—electrical, internal combustion, or other—is called "horse-power."

Our debt to that anonymous blacksmith is immense. Clearly, he had thought his problem through before he drove those nails.

The Internal Combustion Engine

There are times, however, when too much awareness of past experience can handicap inventors. The development of the internal combustion engine—which evolved from the cannon—offers an example.

The formula for gunpowder reached Europe from China by 1260. But in both East and West, gunpowder was used not in guns but simply in rockets, "Roman" candles, and firecrackers, although often for military ends. The cannon was invented in Europe, more than half a century later. It appears at Florence in 1326, and we have a picture of one in England in 1327. The first known Chinese cannon is dated 1332: the idea was probably taken to China by an Italian merchant, for many of them were trading there at that time.

The cannon is a one-cylinder internal combustion engine. Leonardo da Vinci (1452–1519) was the first engineer to glimpse its non-military potential: he tried to substitute a piston for the ball, but failed. Several inventors in the 17th and 18th centuries followed Leonardo's intuition, but without success. The trouble was that all of them were too keenly aware of the cannon as the source of their ideas, so they kept trying to use gunpowder as their fuel.

Not until the 19th century did engineers conclude that powder was too clumsy to run a continuously operating engine. They then turned for their power to the lighter distillates of petroleum—like kerosene or gasoline—that first had been produced by medieval Byzantine and Islamic alchemists for chemical warfare.

In inventing, knowing too much may be as great an obstacle as knowing too little because it may hinder spontaneity.

The Crankshaft

Concern for human safety has often been a motive for invention—as in the case of the crankshaft.

Many of our internal combustion engines today depend on crankshafts for conversion and transmission of motion. Indeed, modern machine design is inconceivable without the crankshaft. It was invented shortly before 1335 by Guido da Vigevano, a famous medic who was then in Paris as personal physician to the queen of France.

Guido was interested in reducing casualties among soldiers pushing siege towers toward enemy walls. If the men could move a tower from inside it rather than from the outside, they would be better protected from enemy fire. So he drew two diagrams of rolling towers, each equipped with a double or compound crank in the center of each of its two axles. He was so pleased with this notion that he also sketched a submarine propelled by paddle-wheels turned from inside by man-operated crankshafts.

Engineers in the French royal service were clearly interested. They developed Guido's device for the theatrical machinery of the great pageants of the court at Paris. In the 15th century, crankshafts became part of the accepted engineering repertory of Europe.

The Parachute

There is one early instance when we can almost look into the inventor's mind at the moment when he produced an invention of much significance for our own century: the parachute.

In London there is the sketchbook of an anonymous engineer, probably of Siena in Tuscany, that dates from the late 1470s and early 1480s. At one point, he seems to be worrying about a friend imprisoned in a tower. Is there any way for the captive to jump and still survive? We see a drawing of a man dropping from a considerable height, his fall braked by two large, fluttering cloth streamers attached to his belt. In his mouth is a sponge to protect his jaws from the shock of landing. He looks terrified—and should be.

The next pages of the manuscript are filled with military engines and the like. But our engineer-sketcher is worried about that man jumping. The streamers won't decelerate his fall enough. Something more effective is needed. So, after 21 pages, our jumper reappears. The sponge is now strapped around his head so that if he cries out in fright he will not lose it. The streamers have been replaced by a conical parachute, the world's first.

A very few years later, Leonardo da Vinci sketched a pyramidal parachute. About 1615 a Hungarian bishop published a book on new engineering devices that contained the first printed picture of a parachute. Thereafter every European engineer knew the theoretical possibility of parachutes; but there were no actual situations in which one was needed.

Only after the Montgolfier brothers of France started ballooning in 1783 did the parachute find a function—to allow descent from a gas-filled balloon. The first human jump with one was made that same year. Our anonymous Sienese engineer had created the idea of a device that remained dormant, although known, for 300 years before it was used.

In our own time, in every major army, parachute troops are the spearhead of swift infantry attack, and without parachutes the manned exploration of space might well have proved infeasible.

In pure science, great discovery, especially if it has technological overtones, occasionally comes by accident or happy chance to researchers. Famous examples are Hans Christian Oersted's observation in 1819 of the relation between magnetism and electricity, William H. Perkin's discovery of aniline dyes in 1856, and Alexander Fleming's of penicillin in 1928.

In engineering, such luck is curiously rare. Inventors seem to have to work for everything they invent.

For them, fairy godmothers are in short supply.

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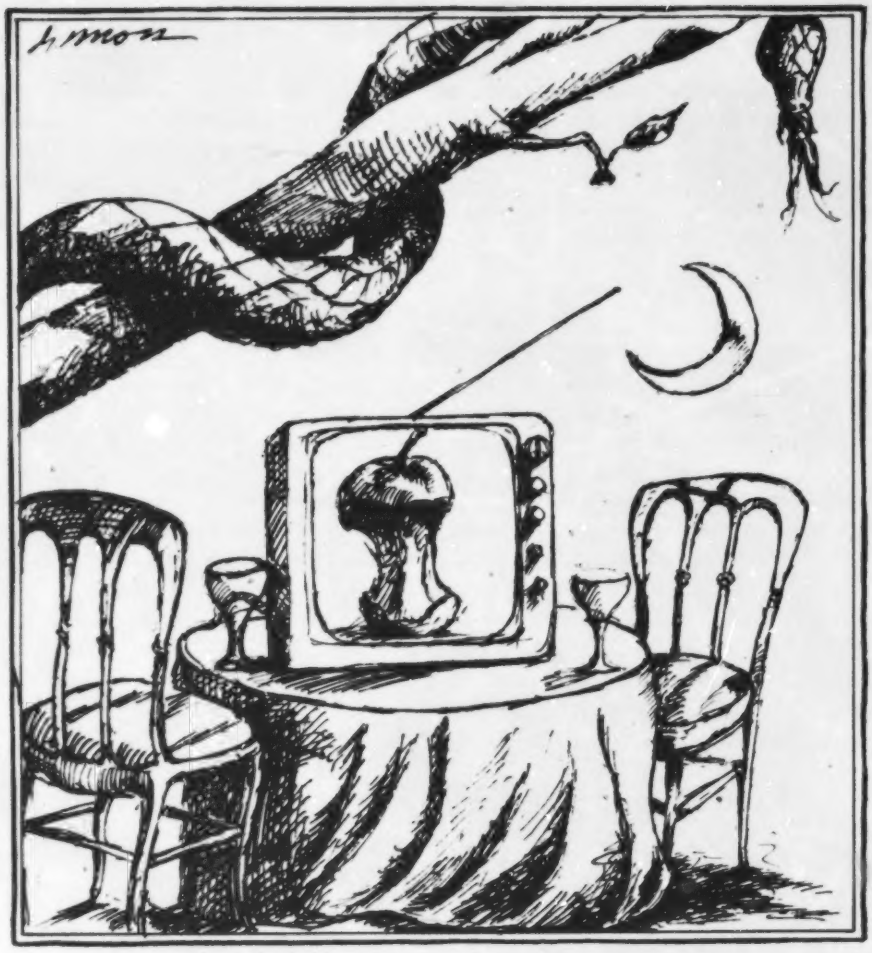

14. Technology and the Seamless Web: Ethical Dilemmas

BERTRAM MORRIS

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Modern technology has had a revolutionary impact upon society, upon nature, and upon human beings themselves.

Technology today has presented us with an unprecedented range of material goods and degree of control over nature. Yet the sheer power let loose by this technology with insufficient respect to human needs has created new ethical dilemmas of ends and means and raised new questions about freedom, justice, and peace in our world.

To what ends will we use the new powers of technology, and what values will guide us in our choices?

Early vs. Modern Technologies

The question of how humans can come to terms with nature has troubled them since Adam and Eve had to fend for themselves outside the Garden of Eden. Technology, primitive in the beginning, provided the indispensable means to secure food, clothing, shelter, and fuel.

But the necessities of sustenance were not all of life. Myth and story and ritual gave meaning to these primitive technologies and relief from an arduous existence. By inventing gods—fire gods, rain gods, sun gods, and other deities—and by interpreting their arts, such as that of the blacksmith, in terms of divine gifts—in such ways myth provided primitives with peace of mind and explanations for those happenings of life beyond human control.

Modern technology relies not on myth but on science and rational engineering methods. The result has been more effective inventions for meeting social and political demands. The machine, the steam (and internal combustion) engine, the hydraulic (and atomic) generator, vaccine and antibiotics, lasers and "smart weapons," and the computer are among its products.

However, science, in replacing myth as the rationale for technology, has not produced a comparable value system, one that really makes us feel comfortable in the world.

Revolutionary Impact

In its reliance on science, modern technology differs from primitive technology both in its revolutionary impact upon all aspects of society and in its stand in relation to nature.

The methods of providing food, drink, clothes, shelter, and fuel are revolutionary—and abundant—from soft drinks to polyester to freeway motels.

Goods have never been so profuse; people have never moved about so much and so far; leisure has never been so widespread; education never so available; and a world of people never so closely tied together.

Modern technology is responsible for the creation of mass society—a society of large-scale industry, massive transportation, world-wide commerce, and a multitude of cities.

The results of technology show also on nature. Atomic bombs, strip-mining, asphalt roads, indiscriminate use of fertilizers and pesticides—these and other techniques have taken their toll on nature.

Mountains have been levelled, the countryside has been industrialized, water has turned green, the air brown—all this and more on a world-wide scale.

In consequence, nature has increasingly become an artifact, a creation of man—or if not man-made, at least man-modified.

But the effects of technology go even further: they show on man himself. While modern technology offers new options, a new spirit of doing things, a challenge to old ways of life, it also offers countless hazards and perils of life—physical and spiritual.

Thus technology, by its very power, creates tragic dilemmas. These dilemmas are questions of ends and means, among which we may single out the crucial ones of freedom, justice, and peace. Together, they constitute the humanistic dilemmas of technology.

Freedom and Choice

Freedom appears to be the legacy of the new technology. Our range of choices is endlessly multiplied by the technology that underlies our tools, our goods, our livelihood.

But this freedom may be more apparent than real. Our cheap pleasures, our reliance on gadgetry, our luxuriant excesses still have to be paid for according to what David Lilienthal called "nature's remorseless arithmetic." The price includes pollution, destruction of the environment, depletion of limited natural resources.

We exert our technological power not only on nature but also on ourselves. The tools we use and the machines we operate make us tools of our tools and robots of our machines. Inexorably-moving assembly lines give us little freedom of choice—or satisfaction from work.

Ironically, we become prisoners of our work, of our baubles, of our debilitating fantasies about them. Increasingly we work not just for the age-old necessities of food, clothing, and shelter, but for luxuries—the color TV, the fancy car, the larger house—which now seem necessary for happiness.

In course, do we not lose our authentic freedom? The dilemma we face is that of how to enjoy the fruits of technology without losing the freedom that is initiated within us. Can technology feed this freedom or does it simply dissolve it?

Freedom is to be measured not by the number of options one has but by the meaning they give to life.

Justice

Should freedom be limited?

If one is to be free, should not all be free? This ques-

tion turns out to be one of justice—namely, that we fashion technology to make available real opportunities for all, not just more for the rich or the powerful.

If our technology denies some of us equality, not just in a formal sense but concretely, then it is a poor thing. A life that concerns the whole society, not one of ease or mediocrity—this is the sort of justice technology needs to serve. It is a technology that is reconcilable with justice—and with an intelligent and compassionate, an exacting and exciting existence—which is its own justification.

Technology does not make inevitable SST's, gas-guzzling cars, and techniques of mind-modifying behavior, whether chemical, biological, or electronic. Technology is not irreconcilable with justice, technocrats are. The difference lies in those who place private goods and the goods of special interests ahead of the public good. Conflict is the result, at home or abroad.

Peace and Power

Thus, our most far-reaching moral problem is the tragic dilemma of peace versus naked power. This was first clearly posed by the Greek poet Aeschylus in the 5th century B.C. in his mythical tragedy, *Prometheus Bound*.

Aeschylus contrasted the immoral, warlike and death-making force of the omnipotent deity, Zeus, with the peaceful practices of Prometheus, who gave mankind fire—the knowledge of technical crafts and other arts that make life livable, make memory memorable, and distinguish waking vision from idle dream. These ends hold good for guiding us as they did for the ancient Greeks.

Technology is at its best today when it contributes to the arts of civilization. It does this through the advancement of the practical arts, such as those that revivify cities, purify air and water, rationalize transportation, employ solar energy, and invent an architecture measured to the human dimension.

Complementing the practical arts are the arts of expression, the song, the colored shapes, the dance, in their endlessly creative forms that supply the kind of vitality to a modern culture that myth did for primitive times.

How to establish these new arts, consonant with the new technology for a new age—this is the dilemma that technology faces in a world of turbulence, despair, and discontent. We need a genuine culture in which humans become an integral part of the seamless web of nature.

The destruction of this web is conflict, whether between nations or between groups of a single society. Only the arts of peacefare can combat those of warfare, and in the process make technology a fitting expression of human well-being.

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15. Assessing and Directing Technology

MELVIN KRANZBERG

Can technology be controlled? If so, how should it be done and, in a democratic society, who is to do it? And towards what ends should it be directed?

These questions involve value judgments as well as technical judgments.

In the past dozen years, the search for answers to these questions has led to Technology Assessment—the attempt by experts, the public, and the government to forecast and evaluate the possible social, environmental, and human consequences of technological developments before they are applied.

Until recently, technology was judged primarily in terms of its immediate—or "first-order"—effects. For example, the immediate effects of the automobile are transportation for its driver and sales for the manufacturer.

However, technology also has many broader impacts—on the environment, on social structure and institutions, on human values and people's lives. These are known as "second- and third-order" effects.

Thus the automobile has led to freeways, suburbs, and a high accident toll. It has affected leisure activities, value systems (America's "love affair" with the automobile), the environment (pollution), and even international politics (reliance upon imported oil).

Along with the benefits of increased mobility, the automobile has had some undesirable consequences. Technology Assessment evaluates the social benefits and compares them with the social costs ("disbenefits") by a process called risk analysis, or social cost/benefit analysis. Action can then be taken to maximize the benefits while minimizing the possibility of socially harmful results.

The possible negative consequences of technological advances were of little concern throughout much of history because technological and social changes occurred at a snail's pace.

Accelerated Change

The Industrial Revolution of the 18th and 19th centuries, however, speeded up technological developments and accelerated social change. As the new machines poured out goods, the old "economy of scarcity" began giving way to the "mass-consumption" society.

Most people approved of these benefits of advancing technology. Nevertheless, legislation to control some unanticipated, undesirable impacts of technical advance became necessary. The U.S. government's intervention in the 1830s to end a series of disasters caused by bursting boilers on river steamboats was only the first of many occasions when the government exercised its regulatory power on technical matters.

For, while technology was changing the face of America, American democracy was demanding an increasing role for government in protecting the public. Thus, today's Technology Assessment can be viewed as another step in governmental action for the public welfare.

Questioning Technology

Although technology's impact had been a social, political and economic issue in Britain and Europe for more than a century, not until the mid-1960s was technological advance seriously questioned in the United States. Why?

The combined impact of Vietnam, the civil rights movement, and the social and cultural aftermath of World War II led to a value crisis and some disenchantment with the "American Dream." Technology inevitably was questioned along with other values and institutions.

At almost the same time, some highly publicized accounts of harmful by-products of technical developments led to mounting public concern: Rachel Carson, in *Silent Spring* (1963) described the danger of DDT; in *Unsafe at Any Speed* (1965), Ralph Nader alleged that car manufacturers ignored safety factors; and in the same period the media publicized the birth deformities from thalidomide, a drug that had been administered to help expectant mothers.

The ensuing public outcry forced governmental action: Thalidomide and DDT were banned; and the government mandated safety belts in automobiles. Almost overnight the environmentalist and consumerist movements came to maturity and "Technology Assessment" was born.

The term was first used in 1966 in a public document by Congressman Emilio Daddario (Connecticut) who asked if it would be possible to anticipate undesirable side-effects of new technologies before they were actually employed.

Congress eventually established (1972) the Office of Technology Assessment (OTA), which joined other agencies in evaluating and regulating the second- and third-order effects of technological changes: Environmental Protection Agency, Occupational Safety and Health Administration, and Consumer Products Safety Commission.

Problems of Assessment

The American people, finally aware of the importance of technology in their lives, were demanding government protection from its possible negative side effects. But there were—and are—problems in Technology Assessment.

First, there is fear that assessing social impacts might delay, and thereby impede, technological advance. Technology Assessment might become "Technology Arrestment."

Second, assessing a given technology's effects is particularly difficult when some impacts are long delayed or

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are dependent upon scale of use. For example, only when employed on a large scale, over a long period of time, was DDT seen to threaten the food chain of birds, fishes, and eventually humans.

Even more difficult to evaluate are the consequences of a combination of technical developments interacting with other social forces. For example, farm mechanization did away with backbreaking labor but also deprived unskilled farmhands of their livelihood. Leaving the farms, they migrated to the urban centers, where they created a serious urban problem because they lacked the skills necessary for employment.

We have finally come to realize that technological changes can have both positive and negative effects. But how can one decide if the benefits of a new technology outweigh its risks? Some people demand that no new technology be introduced if it poses a possible risk to anyone at all. But is it possible — or desirable — to create a risk-free society?

Besides, how do we compare risks with benefits when the dangers might be limited to a small group, such as miners, while the gains might accrue to a larger public, such as producers and users of electrical power from coal?

Furthermore, how do we decide what constitutes a social benefit? How do we measure "the quality of life"? To this end social scientists are developing "social indicators" to measure social impacts.

But is it possible to measure items which really depend on subjective judgments? What are the tradeoffs between, say, driving our cars to work or keeping the thermostats in our homes at 65°? (Or should it be 68° or 70°?)

Values and Actions

These are questions of values. Do we value the speed, comfort, and power that modern technology gives us over our desire to preserve the environment and conserve our raw materials and energy supplies for future generations? Technology Assessment thus confronts us with a basic question: How can we bring our technology into line with our values?

Even if we can agree on values such as liberty and justice for all, there is little consensus on how to translate these values into specific actions. We know, for example, that we must conserve petroleum supplies and control pollution, but most of us continue to drive our cars; it is the other fellow who should walk or take public transportation.

Yet the difficulties of assessing technology should not blind us to its potentially positive role in controlling technology. Technology Assessment conforms to one law of common sense: Think about what you are doing before you do it. Technology Assessment means looking ahead — not just letting the future happen to us.

Technology Assessment also represents a democratic means for dealing with technological change. It insists that technology be used for the good of the whole, not just for a few; it would leave decisions on technologies having major social impacts to the political process — which is exactly where they belong in a democratic society.

The problem, then, becomes one of educating the citizenry and its elected representatives to understand the potentialities and limitations of scientific-technical advances.

Finally, Technology Assessment asserts that we can control our own technology and that we are not the creatures of a mindless technology which could crush us underfoot.

Based upon the premise that we can use our own technology to help bring about the kind of life and society we want, Technology Assessment clearly asks: If ours is a man-made world, why can't man remake it?

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MELVIN KRANZBERG has been Callaway Professor of the History of Technology at Georgia Institute of Technology since 1972 and is generally credited with establishing the history of technology as a separate discipline. Founder of the Society for the History of Technology, he edits its quarterly journal, *Technology and Culture.* He coedited *Technology in Western Civilization* and *Technology and Culture: An Anthology,* and is coauthor of *By the Sweat of Thy Brow: Work in the Western World.* He is the academic coordinator for the Courses by Newspaper series "Energy and the Way We Live."